INRA

LES DOSSIERS DE L'ENVIRONNEMENT DE L'INRA

32

Rio + 20: Research for sustainable development ?

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Rio+20: Research for sustainable development ?

Rio, Johannesburg, then Rio once again: three stages and three *Dossiers de l'Environnement de l'INRA.*

In 1992, the first of these environmental reports comprised six articles published in *the Courrier de la Cellule Environnement* and in *Sauve qui peut!** Biological control, plant diversity, alternative production methods, forest ecosystems: sustainable development in research is achieved in small steps.

2002: Johannesburg. The INRA Environment & Society Team (MES) produced a report in English** and French. It comprised 18 articles published in *the Courrier de l'Environnement de l'INRA*. The report describes sustainable development as being necessary to research in the same way as knowledge production, and as a fundamental aspect of the progress to which scientific research intends to contribute. The INRA, which structurally incorporated environmental issues, prepared to do the same for sustainable development.

2012: Rio+20. The INRA Research/Society & Sustainable Development Planning Team (MaR/S), the MES's successor, produced a report in two languages. It contained 16 contributions, some of them previously unpublished, covering a wide variety of disciplines. The challenge of sustainable development, now incorporated in the INRA's objectives, was gradually revealed in all its complexity: it is as much about knowing "what to look for" as "how to look", "how to innovate", "how to set in motion". A sustainable future depends on the evolution of human and natural systems, and does not lend itself to simplification. In agronomy, thinking "globally" to act "locally" is conceived more than ever in complexity, so as to be able to rise to the challenges of poverty and food security.

*Legrand P. dir., 1992. Rio. *Dossiers de la cellule environnement,* n°3, 64 p.

**Legrand P., Fraval A., Laurent C., 2002. Johannesburg. INRA faced with Sustainable Development: Landmarks for the Johannesburg Conference. *Dossiers de l'environnement de l'INRA,* n°22, 212 p.

***Legrand P., Fraval A., Laurent C., 2004. Johannesbourg. L'INRA face au développement durable. *Dossiers de l'environnement de l'INRA,* n°27, 218 p.

June 2012

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Thanks to Danielle Barrès for rereading
Drawings by Robert Rousso

ISBN : **2-7380-1300-7**
ISSN : **1257-4627**

Impression of 400 copies

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Sommaire

Quotation in bibliography :
Pujol J.L. (coord.) 2012. Rio+20 : Research for sustainable Development ? *Dossiers de l'environnement de l'INRA,* n°32, Paris, 168 p.

Editorial

Marion Guillou

INRA chief executive officer

In 1992, the Rio Earth Summit highlighted the notion of sustainable development. Going beyond the initial framework which was limited to environmental preservation and reasonable use of resources, it also incorporated economic progress and social justice. It was this array which gradually became a new framework of study, research and action. At the same time, through the Heidelberg Appeal, a large number of scientists stressed the need for scientific approaches in the analyse and resolution of problems facing humanity.

However, some of the direct consequences of the Rio Earth Summit included the special roles played by the three international agreements signed on this occasion in the field of climate, biodiversity and desertification.

Interdisciplinarity dedicated to the climate, biodiversity and soils

Undoubtedly, it is the agreement on climate change which has had the greatest impact with regards the organisation of research beyond its own subject. Maybe this is because the IPCC already existed. The fact that all disciplines and all nationalities came together to study the interactions between climate, ecosystems and human societies without concealing uncertainties gave birth to a real scientific community which was not content to simply produce results from its research but which summarised them in a collective fashion and even advised decision-makers. For many people, this operating mode has now become a benchmark.

These methods are now inspiring those involved in the second agreement on biodiversity, because this year, in 2012, the IPBES is to be created. Of course, this does not mean that nothing has been achieved in this field – far from it – but international coordination and a systemic approach seem necessary if we are to make real progress. Biodiversity, as such, is obviously a major subject of research at INRA which, over this period, has been able to increase its level of integration of the environment into its subjects of research, but its sustainable use has now become an important objective: to achieve this, we need to understand all its aspects: specific, genetic, *etc.* The economic, legal and collective framework of biodiversity use has also become a subject of study.

Lastly, the third agreement on desertification has progressed the least, or in any case, it is less internationally apparent. Studies carried out to determine the functions of soil organisms and the large-scale mapping of soil damage and its causes have brought soil science back into the limelight.

With increasing concerns about food security, the fields involved in the last agreement may enjoy renewed visibility. After the 1996 FAO Summit and after the Millennium Development Goals (MDG), adopted in 2000, aimed mainly at reducing extreme poverty and hunger, the subject of food security once again emerged on the international stage in 2008 when "food riots" broke out, and since then this subject has remained a major international concern. This subject will no doubt be discussed at the 2012 Rio Earth Summit.

Whatever the scenarios considered, feeding mankind in a sustainable fashion is a major challenge for societies and for international agricultural research and thus for INRA.

Systemic approaches for action

To identify key elements and alternatives, different institutes around the world have conducted prospective analyses. For INRA and CIRAD, it was Agrimonde. Other international studies, including IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development), the report on rural poverty by IFAD (International Fund for Agricultural Development) or more recently the Royal Society's report, focused on the need for concerted decisions by the various political sectors, which all too often study issues separately, and the need for action based on strong foundations.

The demands made upon agriculture may vary greatly (an increase in current production of between 40 % and 70 %) depending on the conjectured trends in food systems and consumption systems and depending on the actual reduction of loss and waste (today this represents between one quarter and one third of production which is either lost in the fields or else at the time of consumption). The population will increase, food will change according to living standards, the climate will change, land and water resources will be rare, thus exposing the food system to new economic and political pressure.

Therefore, research is expected to act upon many fronts.

Agrimonde

The Agrimonde foresight study was conducted between 2006 and 2008 by CIRAD (Centre for International Cooperation in Agricultural Research for Development) and the INRA, which established two contrasting scenarios for world food systems in 2050. The first, Agrimonde GO, is a business-as-usual scenario that prioritises growth, while the second, Agrimonde 1, is a rupture scenario that considers a world characterised in 2050 by sustainable farming and food.

In summary, between 2000 and 2050, the areas under cultivation increase much more quickly in AG1, with dietary changes most likely representing the most radical shift envisaged. In AGO, gains in yield are the driver for growth in food production and limit the expansion of cultivated land.

Among the factors considered, the anticipated impacts of climate change on land availability and yields were decisive in determining future production potential. In each scenario, projected levels of world food production satisfy projected consumption levels.

The project's objectives were threefold: 1) to anticipate the key questions which research will have to address over the coming decades; 2) to encourage the discussion of food security issues in France; and 3) to promote the participation of French experts in international debates.

The lessons learned can be summarised as follows:

– The evolution of food demand and the levels of loss and waste will be crucial determining factors,

– Trade between the major regions of the world will be more necessary than ever, to make up for the (climate-related) structural and economic deficits of agricultural production,

– As of now, there needs to be investment both in agriculture in developing countries and in training, research, innovation and logistics to promote sustainable production and consumption systems.

Source: Paillard S., Treyer S., Dorin B., coord., 2010. *Agrimonde. Scénarios et défis pour nourrir le monde en 2050.* Éditions Quæ, 296 p.

Of course it is essential to continue exploring the most efficient technologies in the fields of production and conservation of resources on all continents. We must be able to mobilise these methods (these results) and allow everyone to benefit from them – innovation is only worthwhile if populations can put it to sustainable use: Simplistic or partial approaches lead to serious non-sustainability.

Technological innovation alone will not be enough to meet the challenge because the agriculture, environment, food continuum is a complex system which needs to be properly grasped and understood before knowing where and how to act. Therefore, agricultural research also has to deal with the problems of approaches and methods: we must expand our themes, get more and more disciplines to work together on these themes, reinforce the links between science and society – between professionals and various stakeholders – reinforce international cooperation because it is at this level that the research agenda will be decided for these major issues.

Active commitment of agricultural research towards the food system

INRA is already very much involved in this movement. For example, an international research alliance to reduce agricultural greenhouse gases was initiated at the Copenhagen Summit in 2009. INRA also took part in the launch of an international wheat improvement programme and in another research alliance on world food security. Lastly, one of INRA's meta-programmes is devoted to adapting agriculture and forests to climate change. Nevertheless, these are only very specific aspects of INRA's commitment to these issues. Every day we can assess the extent of the knowledge that we lack in the field of living organisms and interaction with the biosphere and planet and also with regards the functioning of societies and communities. In 2011, a committee of international experts was set up under the auspices of the CGIAR (Consultative Group on International Agricultural Research) to study sustainable agriculture and climate change. Its conclusions are unequivocal:

"Business as usual in our globally interconnected food system will not bring us food security and environmental sustainability. Several converging threats – from climate change, population growth and unsustainable use of resources – are steadily intensifying pressure on humanity and world governments to transform the way food is produced, distributed and consumed." Research is called to the rescue.

The aim of this file is to present analyses of various origins on issues that will be discussed at the Rio Earth Summit.

The Joint Programming Initiative on Agriculture, Food Security and Climate Change(FACCE-JPI)

The Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI) consists of twenty mostly European countries* coordinating their national research programmes to tackle the major challenges of providing quality food in sufficient quantity through sustainable agriculture. Approved in October 2010 by the European Council, it is led by France (INRA) and the UK (BBSRC). It sees Member States and associated countries working together around a common vision and strategic research agenda, thereby avoiding duplication, filling gaps and creating a critical mass.

The JPI's first action involves modelling the impacts of climate change and reducing uncertainties in the face of a range of climate change scenarios. It is being carried out by a network of research groups chosen from among JPI member countries, aimed at promoting transnational cooperation, collaboration and communication, and optimising research outcomes by facilitating information exchange. With a budget of € 15 million, its aim is, jointly, to do more and better to tackle these research issues, which are a priority for the future.

Source: http://www.faccejpi.com/

* The countries involved are: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Ireland, Israel, Italy, The Netherlands, Norway, Poland, Romania, Spain, Sweden, Switzerland, Turkey, United Kingdom.

Twenty years after the Rio Earth Summit: towards better research questions?

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After 1992 (the Rio Earth Summit and INRA *Dossier de l'environnement* n° 6) and 2002 (Johannesburg Earth Summit and INRA Environment & Society Task Force reports n°s 22 and 27[1]), in 2012, to coincide with the Rio+20 Earth Summit, the INRA Research/Society & Sustainable Development team presents a new report, the backbone of which is the evolution of the contributions of research and innovation in general, for farming and food in particular.

The report begins by putting the issues into *historical perspective*, reminding us that the "sustainable development" approach has evolved to incorporate new power relations at global level. Meanwhile, whereas the "old" countries recognise very progressively and cautiously the new contributions of civil society, the latter is treated very differently elsewhere. Locally, communities have today returned to the centre of analyses. They are learning new approaches to the environmental management of their land and its development.

Since the first Rio summit, much of the world has continued to enjoy the most extraordinary explosion of prosperity mankind has ever known. This has a lot to do with scientific and technological advances, and a particular energy model. We have as yet scarcely suffered any of the accompanying disadvantages (if one can still call them disadvantage), but they are now very much present. We can no longer content ourselves with the hypocritical old refrain that technical and scientific progress alone, in whatever guise, will solve the problems that are mounting up for our grandchildren. Various factors have altered the outlook; in particular, scenarios concerning the earth's evolution have become certainties in substance, and their consequences need to be analysed. From this perspective, the report recalls the *many challenges* facing societies**.**

In 2002, the INRA's Environment & Society team's *Dossier* included 18 articles of the *Courrier de l'Environnement de l'INRA*, focusing on sustainable development as a new dimension of progress. It drew attention to the possible denial of the research community in the face of this new dimension which, at the same time, is beyond its control. An inventory of points of friction and question marks between the main body of research by discipline and sustainable development issues showed how no issue escaped these new expectations. Since then, the question has also been raised as to the reasons why certains issues and phenomena have been unjustly forgotten by decades of carefree growth and progress. Thanks to the Intergovernmental Panel on Climate Change (IPCC), the community of scientists and decision-makers has reached agreement on a core of assertions and issues relating to climate change, concerning both how to combat it and how to adapt to it. The international scientific community is attempting to organise itself in the same way for biodiversity[2]. Agricultural development has also been the subject of multidisciplinary, multidimensional and multitemporal intergovernmental processes[3], with a governance similar to the IPCC or the Millennium Ecosystem Assessment

1. Legrand P., Fraval A. and Laurent C. (2002) *Johannesburg. INRA faced with Sustainable Development: Landmarks for the Johannesburg Conference*, Dossiers de l'Environnement de l'INRA, n° 22, Paris, 206 pages, and *Johannesbourg – L'INRA face au développement durable.* Dossiers de l'Environnement de l'INRA, n° 27, Paris, 206 pages.

2. Through the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services).

3. Co-financed by the Food and Agriculture Organization of the United Nations (FAO), the Global Environment Facility (GEF), the United Nations Development Programme (UNDP), the United Nations Education, Science and Culture Organization (UNESCO), the World Bank and the World Health Organization (WHO).

(MEA)[4]. In 2008, the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) presented some powerful conclusions. We are seeing the development of an approach which harnesses scientific progress to global issues.

Since 1992, the paths of agricultural innovation have been much discussed, and not only in Western countries. The example of GMOs – which we will not take up again in this report – is salutary: beyond the questions concerning the risks and opportunities they present, it is the agricultural models they involve which are discussed, right down to the workings of the economic and policy mechanisms of rural and agricultural societies. Beyond even what they are biologically and physically, more often than not they emerge, like many other innovations, as part of a process of simplification, even though it is the whole complexity of agrosystems that needs to be re-evaluated.

The independent positioning of the most accomplished technologies appears inadequate to rise to the challenges. A scientific approach which, in order to home in on theoretical models, segments the factors, isolates performance and reduces variability, continues to struggle to address the great diversity of the real world. In these conditions, we may indeed develop the most efficient cow, the most advanced irrigation system, the highest-yield variety or the highest-precision practices, which bear no comparison with what was available 20 years ago. Why, then, with so many "best available technologies" on the shelves, does the solution to our problems continue to appear uncertain? The uncertainties inherent to the scientific approach have, in a good many spheres, become at least as sizeable as the established knowledge: legitimate doubts, they are also exploited in controversies[5]. They also lead to changes in the course of human progress, and can even conceal significant, irreversible changes. The world of agricultural research in all its diversity has found itself faced with questions on the major advances in the managing of living resources and the emergence of limits and handicaps, and even on the paths of progress taken and the possibilities of altering them. These changes are at the heart of the *agronomy on the move* section of the report.

The very nature of necessary knowledge and research, sources of knowledge and paths of development is changing. For example, while genetic research on such and such a grain would appear always to be a necessity, it is in response to broader expectations than simply the increase of quantitative performance. The Green Revolution of the 1960s was based on the yield performance of new varieties, drawing on agricultural development models of the countries of the North, and led to the belief that intensification could save ecosystems. That is now less certain, and the need for ecological functions in production areas emerges once again, since ecosystems themselves provide extraordinary services to mankind[6].

The last part of the report presents a few examples of what *knowledge flows* are needed, which are not always in a North-South direction. It implicitly highlights the fact that the geography of the world is no longer what it was in 1992, in economic and political terms, clearly, but also in terms of knowledge.

This report does not look at all the issues raised in Rio. For those it does not address, there is a huge amount of work under way. For those it does address, it shows how advances, however unequal, have been made, some of which also reveal new issues that cannot be resolved exclusively by means of the most cutting-edge technology, but which nevertheless involve some real research questions. New knowledge needs to be developed on all kinds of systems, with the most advanced research tools and the right actors addressing the right questions: in any event, the most simplistic solutions, as far as their method of formulation or application are concerned, no longer have any place here!

4. The Millennium Ecosystem Assessment was an international work programme which, between 2001 and 2005, brought together hundreds of experts to draw up a state of the art of knowledge on ecosystems and the services they provide.

5. Doubt-mongering lobbies have got involved, going so far as to raise doubts as to the mechanisms of scientific validation themselves, for not always laudable reasons.

6. Work by the MEA and work by Pavan Sukhdev: *The Economics of Ecosystems and Biodiversity* (TEEB) study.

I. Preamble

The 1992 Rio Earth Summit: a look back at the history

Bettina Laville

Founding Chair of Comité 21 and Chair of the Forward Planning Committee

Comité 21 is a not-for-profit organisation founded in 1995 to nurture, in France, Agenda 21, the action plan for the XXIst century ratified at the Rio Earth Summit by nearly 170 heads of state and government. On 4 July 2011, it held a forum at Palais Brongniart, in Paris, on the different national and international commitments concerning sustainable development that are due to expire in 2011, and in preparation for the 2012 Rio Earth Summit, "Rio + 20", twenty years after the 1992 Earth Summit, considered the beginning of widespread sustainable development initiatives. At the forum, Bettina Laville, Founding Chair of Comité 21 and Chair of the Forward Planning Committee, looked back at the history of the summit, since at the time she had been the Prime Minister's coordinator of the French positions. Her speech is reproduced below.

Hello,

You have asked me to talk, at this round table, about the history of the Rio Conference. As part of my role at the office of the French Prime Minister, I was coordinator of the French positions for Rio in 1992. I think you are all familiar, to varying degrees, with what is associated, historically, with Rio; so, rather than going back over the history itself, I would like to focus instead on an "informed" history, if I can call it that, and at the differences between "Rio 1992" and "Rio 2012", commonly referred to as "Rio + 20".

The Rio Conference – also known as the "Rio Summit" or the "Earth Summit" – is a conference of the United Nations, which was prepared for over a three-year period prior to taking place. But it should be remembered that two other major events laid the foundations for the 1992 conference.

The first is the United Nations Conference on the Human Environment, which took place in Stockholm in 1972. You will notice how – not insignificantly – we do not say "Stockholm+40", but instead "Rio + 20". Although Stockholm was the first conference to put environmental issues on the international negotiating table, it did so in a very different format from that of Rio, twenty years later: first, because it was a very European conference; second, because the mobilisation around Stockholm was not on the same scale as for Rio. Stockholm was a conference of informed experts, whereas Rio was a genuinely global conference involving all the parties concerned, later to be termed "stakeholders" (though they weren't at the time). In Stockholm, the decision was taken to put in place a specific programme for the environment, which led to the founding of the United Nations Environment Programme (UNEP). So we could say that we are at "Stockholm+40" as much as "Rio + 20", because in June 2012, in Rio, we are to debate the setting up of a World Environment Organization (WEO), of which UNEP, in some shape or form – even if we do not know exactly under what guise – will be the pivot, or at least an important pillar.

The second major event which laid the foundations for the 1992 Rio Conference is obviously the Brundtland Report[1], which put the notion of "sustainable development" on the agenda of

1. Published in 1987 by the United Nations World Commission on Environment and Development, the Report *Our Common Future*, known as the "Brundtland Report", was named after the Norwegian Chair of the Commission, Gro Harlem Brundtland.

international negotiations and advocated a joint approach to environmental and development issues. The Rio Conference was a conference on the environment AND development. These two notions were both extremely important and equally essential, yet six months prior to the conference, we were on the verge of collapse. The four or five months leading up to Copenhagen reminded me a great deal of the run-up to Rio. But it has to be admitted that in Rio the leaders were far more proactive, and that slightly more positive things happened there than in Copenhagen.

Finally, there were two major issues on the negotiating table in Rio in 1992: the main issue of environmental protection, and the call for equality in development. Principle 4 of the Rio Declaration summarises it the best: ”In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.”

Over the three years leading up to the Rio Conference, the countries of the South insisted more and more forcefully that development issues should be given priority over environmental issues, which can be thought of as a test for environmentalists, since the environmental content of the Rio Declaration was completely watered down as a result and the idea of a great Earth Charter did not, in the end, materialise in the form of an international treaty, although a number of “lesser” Earth Charters did come into being, supported by Maurice Strong, the then Secretary-General of the Rio Conference. Environmentalists aspired to the implementation of a “right to the environment”, but this notion was completely swept aside by the countries of the South, who reasserted their “right to development” and insisted on the fact that international environmental legislation would lead to international litigation and hence international penalties. The countries of the South had no intention of being penalised for their “bad” environmental conduct after the “colonising” countries of the North had plundered their resources. This issue put considerable strain on relations and was at the heart of discussions up until September/October 1991.

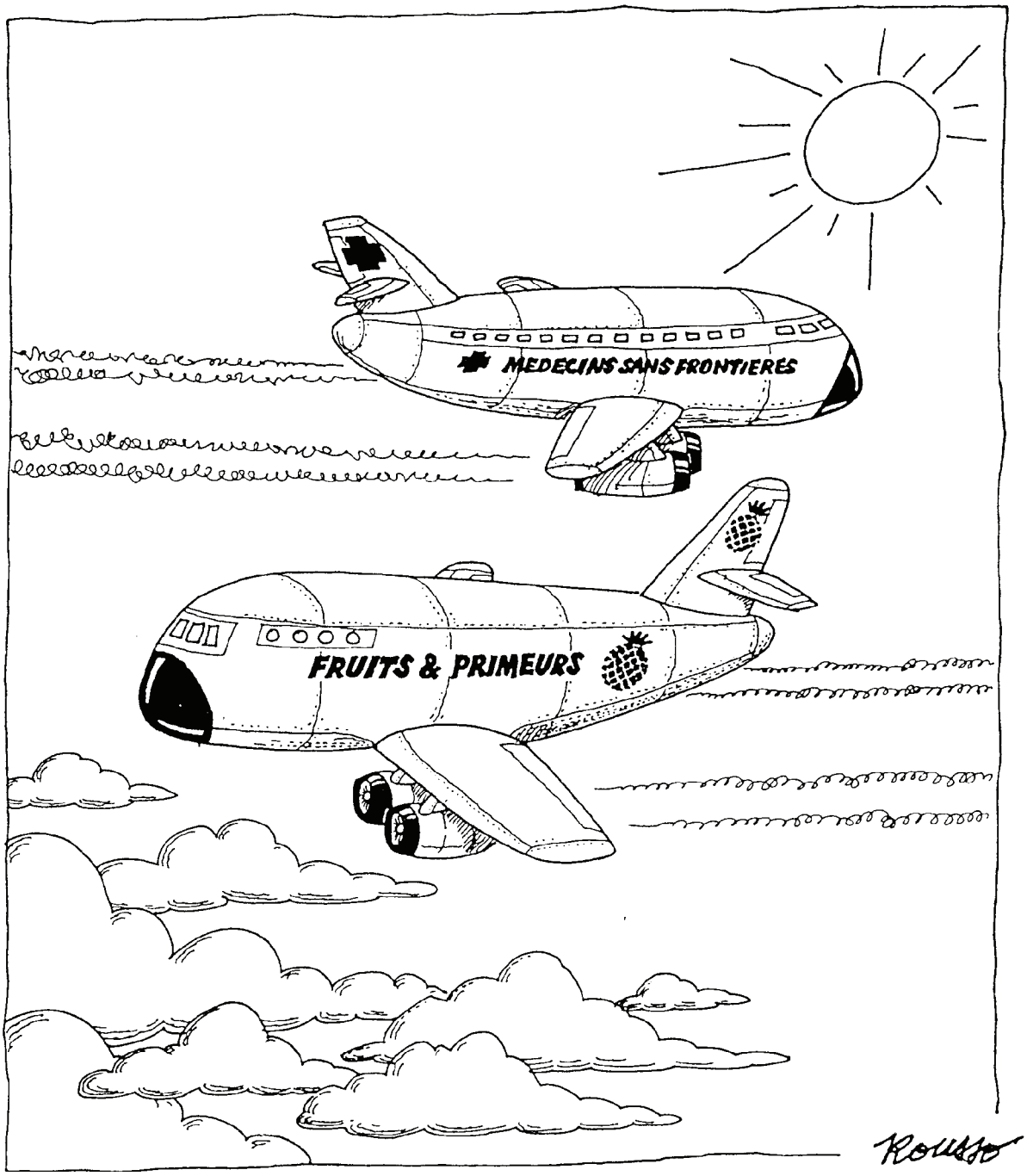
However, in spite of the tension, the Rio Conference was a success. This was for a number of reasons, in particular the fact that, at its helm, were some quite remarkable individuals. I am thinking especially of Jean Ripert, negotiator of the climate change convention, who had been United Nations Director-General and knew all the heads of delegation, and who was able to “knit together” a very “balanced” text. He deserves a special mention because he was a man of extraordinary determination. We might also mention Yves Martin, who died in December 2010. Yves convinced Jean Ripert on the scientific aspects and put all his talent into the convention.

I would like to insert a parenthesis here, which represents entirely my own point of view: It must not be thought that environmental conventions should be negotiated by the experts; there is no shortage of examples to show that this often leads to failure. The experts are there to inform, the diplomats to negotiate. In order to achieve a successful outcome, you also need “professional” negotiators, and they are the diplomats. I am entirely convinced of this; diplomacy is a skill. I also think that the very mixed results of the Copenhagen Conference had above all to do with the fact that the experts took the upper hand in various countries, including France and the United States. The experts are not always satisfied with the results obtained by the diplomats, but, to put it in a nutshell, with the diplomats there are results; with the experts there is controversy, in Las Casas’ sense.

Part of the success of the 1992 Conference can also be attributed to the fact that the “awkward” issues were left to one side, enabling negotiations to run much more smoothly, in particular the Convention on Biological Diversity. Those awkward issues, concerning in particular the sharing of benefits arising from the seed trade, began to be addressed in Nagoya, in 2010.

On the issue of climate change, it was decided that discussions on global warming should be postponed, but without establishing a timetable or order of priorities, and progress began to be made in Kyoto, in 1997.

Obviously, the Conference was not all successes. In this respect, I would like to take a few moments to look back at the Biodiversity Convention, which was seen as an affirmation of the defence of both nature and biodiversity. Once the countries of the North and the International Union for Conservation



Drawing by Robert Rousso *in le Courrier de l'environnement de l'INRA* nº 20.

of Nature and Natural Resources (IUCN) had accepted the fact that each nation was responsible for conserving its own biodiversity, there were no more problems, because there was no longer international sovereignty over biodiversity. But this is regrettable, because that "national" choice led to all the work of UNESCO, which had introduced the global dimension to natural and cultural heritage, being undermined by the Biodiversity Convention. It can therefore be thought of as a failure, since Rio was the first international conference to confirm the impossibility of universalism, leading

to some of the difficulties that followed. This hope, this utopia in which all countries might agree to respect the earth's shared assets, did not survive the preparations for Rio. A right was established, but let's stop calling it a right to shared assets, because that remains highly theoretical.

But, as I was saying, the Rio Conference also brought many successes which can be celebrated. It was the first time that the international community really mobilised around vital issues of life, survival and preserving the earth's balance. We can also credit the Rio Conference with addressing the phenomenon of desertification, already very much in evidence at the time. Although the convention was not completely ready in 1992, everyone knew that progress would be made, because certain countries, France in particular, had "seduced" African countries by promising a Convention to Combat Desertification, which was signed at UNESCO a year later – one of French President François Mitterand's final acts. Today, that Convention "functions" reasonably well, despite insufficient resources, and even if the desert continues to advance.

Meanwhile, we can only lament the fact that, despite the treaties and conventions, global warming persists, biodiversity is diminishing and desertification is increasing. It is a situation which, to my mind, is particularly important in the light of the past two decades. Mankind, aware of the changes brought about by its lifestyle – FORTY YEARS of negotiations are proof of this fact – continues to chase after a solution to worsening problems, without being able to manage them.

I would like to add to what I've said so far by making a number of points.

Firstly, the NGOs which, around the world, and particularly in Brazil, prepared the Rio Convention, found themselves torn between their own universalistic, supra-national approach and an acknowledgement that the only way to respect the countries of the South was to ensure the acceptance at the summit of the idea of "sovereign nations". Brice Lalonde – for whom I was private secretary at the time – and myself came up with the idea of inviting all the NGOs to the Cité de la Villette, in Paris. There, President Mitterand made a speech which I would describe as his "second Cancun speech"[2]. He really connected with the issues; he used the handful of keywords that were expected concerning the sovereignty of nations and the Environment Plan; and he reiterated the promise of the famous 0.7 % of GNP which all rich countries were supposed to commit to development (a promise which, twenty years on, we realise is largely utopian, since that figure has never been reached, except by the Scandinavian countries and, in one year alone, by France – and then only if funding to the overseas departments and territories, or DOM-TOMs, is taken into account). As a result of the La Villette conference, negotiations were resumed and we regained the support of NGOs, who accepted the contradiction between a desire for universalism and a need for national sovereignty.

I would like to make a second point about Rio which concerns the drawing up of Agenda 21, because this extremely important work was largely overshadowed in the negotiations, which focused entirely on the treaties. However, all that was negotiated, in an extraordinarily lengthy process lasting nearly two and half years, also contributed to Agenda 21, which is to some extent an international agenda. If the earth were Rousseau's *Emile*, Agenda 21 would be Emile's education, in other words, a learner's guide to making our planet the best possible in all aspects. Agenda 21 is the only text in the world to embrace every single area where mankind is able, firstly, to collaborate with all its constituent parts and, secondly, to have an impact (or rather, less of an impact) on nature. Agenda 21 therefore remains extraordinarily current.

Another observation is that the conventions that came out of the 1992 Rio Conference were ratified and are functioning, even if, for the past four years, we have been in a severe state of aporia. That in itself is absolutely incredible, given how new the theme was at the time, both in terms of its content and in diplomatic terms. We are bound to lament the ever current paralysis of the past five years, yet in terms of the age of international diplomacy, it is an extremely short time given the importance of what is at stake.

2. In reference to the speech given by President Mitterrand on 20 October 1981, before the Monument to the Revolution in Mexico City, known as the "Cancun Speech".

I once wrote in an article that we were seeing for the first time an "international scientific diplomacy", an osmosis between the role of the diplomat, which I mentioned a moment ago, and scientists. For the first time, we were able to rely on this kind of partnership, where the diplomats rely on the IPCC (Intergovernmental Panel on Climate Change), which addresses the policymakers directly[3]. These were entirely new methods of partnership and negotiation, with the proviso I gave a moment ago: the need to effectively combine the actions of diplomats and experts.

I think the great failure was not Copenhagen, but Johannesburg, because – as I said at the time, attracting much criticism – was a retrograde summit, a summit which split up the environment and development that we had worked so hard to bring together in Rio, and which decreed that the private sector could take care of environmental progress through green technologies, while the public funding that came out of the Millennium Summit would be devoted to the issue of poverty. The problem is that not everything can be achieved through green technologies alone; some government action is also required. Besides, as you know, the Millennium Development Goals[4] are nowhere near being achieved today. The weak link is therefore the Johannesburg Summit, although Copenhagen, too, was in some ways a failure, because it was a summit that was poorly prepared, over-hyped, with too many expectations, leading to dissatisfaction in the end. The same fate nearly befell Rio, because Maurice Strong had put forward ambitious targets with astronomical figures, which were obviously not achieved.

I also think that, looking back over the past twenty years, we need to stop pledging sums of money to poor countries which we are completely unable to give them – even at the time of pledging. I believe that, from this point of view, progress has been made with the creation of a Green Fund (a fund to support poor countries facing climate change), which it seems to me is a slightly more realistic initiative, even if the economic crisis in the West is slowing down the process.

With Rio+20 just months away, we can safely say it will be very different from Rio 1992, because the geopolitical situation is completely transformed. Rio 1992 was a little window at the end of what was admittedly quite an eventful XXth century, including in Europe, particularly with the fall of the Berlin Wall. The whole of Central and Eastern Europe had to be included in the international negotiations as new states, yet since the reality was actually rather different and they were still only fledgling nations without any real diplomatic voice, they were incapable of putting up any opposition within Europe.

Secondly, although at the time NGOs were considered to be a "spur", they were not yet actual stakeholders. But they nevertheless played an important, if parallel, role in Rio – but then all the parties in Rio acted in a parallel capacity. What was crucial was the summit of heads of state, because this melting pot of all actors – local authorities, NGOs, businesses – was something that had not been seen before.

Thirdly, local authorities have become important elements and will continue to be at the approaching Rio Summit. They organise themselves at each summit, conduct their own negotiations – we see it in relation to climate change – and work both within their own international organisations and among themselves on the evolution of the environment and support for development. That was not the case in Rio, in 1992. Local authorities and a great many local councillors were present at the time, but they were there as personalities, not as a negotiating group. That has completely changed today. Companies, meanwhile, were either "anti" and were there as onlookers, or else were firmly strongly involved but quite isolated, and in Rio they used economic avoidance strategies rather than "stakeholder" strategies, to use what has become the accepted term. This, too, is entirely the opposite today. I find companies discussing what their strategies should be in relation to Rio+20 and, above all, reporting has entirely changed and widely developed. Companies, too, have become decisive actors.

3. See preambles to the IPCC reports: note for coordinators.

4. Goals drawn up by the UN General Assembly in September 2000. The resolution setting out all of the goals can be viewed online here: *http://www.un.org/millennium/declaration/ares552e.pdf*

Lastly, while Rio 1992 advocated the famous slogan "Think global, act local", coined by René Dubos at the first environmental summit in 1972, I believe that Rio was a movement of the global to the local. Agenda 21 asked local authorities and all communities to draw up a list of themes. A huge number of things can be seen going on today on the ground and in communities. Companies, NGOs, local authorities and citizens have taken on, to varying degrees, the risks linked to climate change, loss of biodiversity and so on, and are beginning to act. So if there is one success we can hope to come out of Rio + 20, it is that it might truly herald the advent of the local to the global. Today, the local level is where this international community, which is struggling to emerge from states alone, can be rebuilt. One of the major failings of Rio 1992 was that we did not succeed in making the environment and development – the issues on its agenda – a matter for the UN Security Council, or at least the Economic and Social Council. The idea was there, but it came to nothing. All that was achieved was the election, by the Economic and Social Council, of the representatives of an *ad hoc* commission, the UN Commission on Sustainable Development. Despite being put in charge of monitoring the Johannesburg Plan of Implementation, the Commission's last session was acknowledged as a failure.

Since we are at Comité 21, I would like to end by quoting Serge Antoine, Comité 21's first chairman, which remains incredibly current. Serge was at the UN at the time, to prepare for the Rio Summit. I would say he was no longer a "French Mr Stockholm", as he had been, but the Brice Lalonde of the time:"Sustainable development policy can be refined. It is made on the move, a bit like the invisible man who becomes visible when bandages are laid on him. We need to be aware that we are dealing with a real cultural revolution, a revolution of behaviour, in particular political behaviour, to which our usual systems of analysis are alien. I will not go into all that is needed for sustainable development to be taken seriously. Let's just say that we must avoid pursuing a purely environmental approach and that we need to draw systematically on economic, cultural, social and ecological sources, that it is essential to plan further and further ahead, that we need to transform everyone into 'actors' and if possible set up multi-actor operations, that we must make use of the voluntary sector, and that monitoring indicators are indispensable. I won't say much more than this: the movement has been under way for two or three years now in companies, local authorities in France are setting things in motion, and it is encouraging to see different sectors gradually getting involved."[5] Serge had understood it all, said it all, grasped it all, and since I was asked to look at the history of the summit at this round table, I wanted to pay tribute to him, because he symbolises the path from Stockholm to Rio, the handover from pioneers to actors. And here we are today, handing over ourselves from "Rio 1992" to "Rio + 20", a crucial step because, the more we say that tomorrow it will be too late, it really is getting late, you know...

5. Serge Antoine, in *Revue Urbanisme – Villes – Sociétés – Cultures*, nº 336, May/June 2004.

Sustainable Development, anatomy of a notion[1]

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Sustainable development, as defined, explained or implemented over the past two and a half decades, is not an univocal question or practice whose inherent truth may be clearly stated[2]. It is not an obvious notion, a future whose values and institutions will be shared, a common necessity which everyone will hasten to implement. If we take a pragmatic stance and consider things in their diversity, it is rather a syntagma with a great variety of uses, a set of convictions, practices and institutions full of variable meanings; moreover it is an economic challenge and political battle between societal projects. In this paper, I intend to systematically review some of these meanings, as they appear in concrete terms nowadays, in order to understand what is at stake in the situation in which we find ourselves.

An ideal for society and life together

In historical terms, sustainable development is above all a societal project, a choice of life together on Earth, an ideal given to guide collective action. To summarise what is well known and what has been a common fundament since the Brundtland report, I would say that this ideal is based on three principles[3]. First of all, it is an ideal of social justice for the people who live on the planet, an ideal for today and for future generations. Secondly, it is an ideal of precaution and environmental justice to integrate into social and economic development projects. Finally, it is a political ideal, an ideal of cooperation and participation in decisions and choices. The fundamental reason behind this last point is that open public debate mobilises different types of know-how, undertakings and personal experiences – and could thus better anticipate problems and their complexities, and invent the most appropriate solutions.

This ideal of sustainable development presupposes values, *i.e.* a certain perception of the good life for societies and for the Earth. It presupposes an analysis of possible solutions – via science of course, but also by mobilising other forms of knowledge and other ways of approaching problems. It also presupposes multiple scales of action – from global prevention (of climatic warming for example) to local adaptation. It assumes cooperation between these various forms of knowledge and judgement, and the definition of rules, objectives and common priorities. It assumes reasonable exchanges, constructive debate conducted in good faith, a dialogue whose conclusions must be integrated into our modes of economic and social development. It assumes the creation and implementation of a set of measures and reforms – more particularly the pronouncement of rules and principles for public action, social and environmental action and for the organisation of the markets.

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1. This text was first published as a paper in french (2011): Développement durable: anatomie d'une notion. *Natures, Sciences, Sociétés,* 19, 1, 31-39 © *Natures, Sciences, Sociétés.*

2. Zaccaï (2002), Vivien (2005), Aubertin and Vivien (2010), Larrère and Larrère (1997). See *Eco-Rêve, n° 38*, 2012 and *Quaderni n° 76,* 2011.

3. World Commission on Environment and Development (1987).

Finally, it assumes methods for judging projects carried out, via various indicators and *dispositifs* – new kinds of balance sheets ("green accounting") for example.

The origin of this ideal can be found in the debates on the environment and the nuclear question of the 1960s. It can be found in 1971 Stockholm Conference and all the conferences that followed – right up until the Brundtland report and the Rio Earth Summit which give kind of universal credence to the term sustainable development itself.

If I had to use an expression that sums up the nature of sustainable development as a political project and describes the values, desires and principles it originally embodies, I would say that "sustainable development" is the name given to a fundamentally "ecological social-democratic" project. I have chosen this expression (that I intend as an ideal type which refers to no concrete or historically based social democracy) because sustainable development promotes a society that wants to be consciously reflexive; because it promotes, alongside properly controlled market activities and consumption, the importance of collective elaborations (of which the Kyoto Protocol is an example); because it believes that the human spirit and dialogue are capable of understanding and improving life; because it is driven by an ideal of social justice and environmental protection which strives to be cautious and redistributive – and these characteristics seem to correspond to social-democratic philosophies which became ecological.

In other words, this societal project is in line with Keynesian thought extended to include an environment considered a new partner. It believes in the possibility of setting out objectives for the common good and achieving them (even if this is partial and not devoid of problems). It believes, contrary to Hayek's opinion, that markets cannot be left to their own devices, that they must be regulated and defined according to rules that favour sustainability – because markets regularly lead to negative impacts on the environment and the disintegration of society. In short, it is an ecological and social-democratic project since it believes that the common life should be considered and deliberated upon, since it believes that it should be conceived via collective thinking, via reasoning and exchange.

An ideal confronted with other logics

This development project is confronted with the fact that societies in which it plays a part are not governed by the unique principle it advocates but by contradictory and manifold principles, interests and modes of action. Indeed, our societies are liberal societies from a political and economic point of view; they are rooted in nations and in the defence of their own interests; they are societies, at least in some countries, with representative political systems which claim to govern via discussion and choice. They are societies of individuals whose rights to self-government are defined and protected; they are market societies in which business people compete with each other and strive to maximise their profits; societies which are politically organised into Nation States based on elected governments – and even "global" societies governed by international organisations and agreements. Unfortunately, these logics are not tension-free; our societies are not integrated groups – and this intrinsic variety is no accident: according to Benjamin Constant (1819), this is the basis of "the Liberty of the Moderns[4]".

To keep things simple, I shall discuss two levels of tension between these complex realities and the ecological social-democratic project which sustainable development actually is. The first tension is between the logics of rivalry and competition for survival and supremacy, and the logics of drawing up collective solutions between people of good faith. The tension is between the logics of markets and consumption, the logics of entrepreneurs who are free to innovate, produce and sell, the logics of States which defend their sovereignty, the privileges of their constituents and those of their industries which provide jobs – and which are therefore based upon the defence of their essential interests –

4. Constant (1819). For a parallel framework, Fitoussi (2004). For a broader study, Derrida (1994).

and the logics of collective choices, the idea of cooperation and even mutual aid as vehicles of efficiency. Of course, we can dream of a world in which these two logics could be reconciled, a world in which the harmony of the Enlightenment would prevail, but resistance to these two frameworks has become very powerful and we cannot ignore it.

The second tension comes from the different time-frames of these two spheres. The first sphere is based on short-term action, while the second sphere's reasoning aims at long time-frames. What is important for the first sphere is a rapid and immediate return on investment, the protection of well-understood interests of States, individuals and *entrepreneurs* – and its assessment criteria are not mainly concerned with an abstract idea of public interest, but with specific advantages that can be obtained immediately for its own benefit. In the case of commercial activities, new products are distributed via markets according to time-frames which producers have an interest in reducing. These offers transform the world regardless of any preliminary debate – even if it is possible to format the markets so that they integrate certain requirements – and any negative global effects on the environment, public health or ways of life only appear through usages and thus over time. Human-environmental collective groups affected by these technical deployments are therefore placed in a reactive position, and it takes them time to understand the consequences and to adapt. Admittedly, it is possible to anticipate consequences when launching products but action which challenges unintended effects of technologies can only be deployed later, in a second move, once the consequences manifest themselves. And as everyone judges the advantages and drawbacks of these new products in different ways – as these judgements depend as much upon well-understood interests as upon generous anticipation – this temporal asymmetry is a handicap for precaution.

To illustrate this twofold tension, I shall take the example of geo-engineering for Earth system projects which aim to reduce global warming[5]. For the moment, these projects to artificially modify the climate or "fertilise" the oceans are still under study. However, they are the subject of numerous conferences and reports – one of the most important one being the report produced by the Royal Society in 2009[6]. In this document, the view is two-sided. According to the report, we cannot ignore the catastrophic consequences of meteorological geo-engineering tests carried out in the 1970s which led to flooding and agricultural disasters, and we must be cautious when dealing with phenomena of this size, which we do not really understand. On the other hand, the report suggests that they are realistic solutions that we should study and prepare to implement. Even if tests are carried out (some have already started), the effects will only be felt later when things are actually implemented *in full scale*. Indeed, they may have very different effects depending on geographical regions; they may result in some regions and populations on earth suffering serious deterioration to their environmental equilibrium. More important, if these actions are authorised within a market framework, which is actively encouraged and perfectly in line with changes that have occurred over the past three decades – *i.e.* if companies are authorised to carry out action in order to obtain assets on carbon markets, assets that they can sell to those who need quotas – it is reasonable to assume that it will be in the interest of these companies, in compensation for their investments, to act vigorously to obtain a large number of pollution rights. In this case, the potentially negative effects may be multiplied – in the name of sustainable development enabled by the reduction of greenhouse gases.

Therefore, the notion of sustainable development is an oxymoron; it is a useful oxymoron in that it stresses the importance of bringing together societal, developmental and environmental issues but nevertheless an oxymoron since it masks or ignores the complexity of situations and the variety of implementation methods possible. It is useful because it highlights essential problems in these times of crisis for the climate and biodiversity, because it provides objectives for action (*via* scoreboards or statistical data), because it may encourage manufacturers and politicians to reappropriate these values and because the public sphere can take it on and "impose" it as a standard that carries weight.

5. For this paragraph and the following see Kwa and Van Hemert (2011). See also *http://climateresponsefund.org*
6. The Royal Society (2009).

Symmetrically, however, there is no unequivocal interpretation of what sustainable development suggests and there is no simple and unique solution nor solution devoid of pernicious consequences in market-based societies[7].

An expression widely used in the public sphere

However, sustainable development is more than a new development concept confronted with realities and modes of regulation acting against it or regardless of it. In recent years, the expression (because it is a widely used expression in the public sphere) has also become an often used "slogan" with very variable meanings. It has become a commonplace which operates like an all-encompassing norm, a malleable leitmotiv that all people claim as their own but interpret freely[8]. In the media, the term "sustainable development" has become the new meaning given to responsible and positive progress that we should all embrace. It is part of Newspeak which has gradually developed over the past decades and which includes well-known expressions and statements of principles: "good governance", "transparency", "voluntary commitments", "public-private partnerships", "stakeholders and participation", "soft law", *etc.* Sustainable development is part of the new ideology of the XXIst century, as Zaccaï says, which fills the radio waves and newspapers, has its place in schools and on the web, is presented as a Good principle, admittedly vague and flexible, but which nobody can challenge without risking rapid delegitimisation[9].

Therefore, it is not surprising that, alongside pioneers like environmental NGOs and the UN (through the United Nations Environment Programme set up in 1972 following the Stockholm Conference), major institutions in the "Washington Consensus" (and the OECD of course) rallied to the idea and made it one of their watchwords. Likewise, for the past decade or two, many companies and politicians have been claiming that sustainable development is their priority and that it guides their action – for many reasons: because electors and consumers seem to be very keen on it, in Europe at least; because its implementation will allow manufacturers to create new markets; or because, by enacting new "sustainable" standards, they will be in positions to undermine their rivals' strong positions. The World Business Council for Sustainable Development – "a CEO-led organization of forward-thinking companies that galvanizes the global business community to create a sustainable future[10]" – was set up in 1995 while on 31 January 1999 in Davos, Kofi Annan launched the Global Compact aimed at the business world and in 2002, the Johannesburg Summit placed "Type 2 initiatives" (PPP or Public-Private Partnerships) at the heart of its recommendations, in order to meet the challenge of sustainability.

These partnerships – but more generally any marketing of nature or the damage we inflict upon it – are based on three principles[11]. The first is the need to define a metric, a simplified and if possible unique standard to regulate action and trade, and evaluate the effects. With regard to climate change for example, it is carbon emissions. For biodiversity, the work of the experts consists in allotting values (prices) to the "services" that ecosystems provide – which allows the eco-system services market to be set up[12]. Secondly, it is a matter of specifying and defining property rights. With regards genetic resources for example, promoted at the Rio Summit, the rights of indigenous populations which possessed traditional knowledge were determined. Companies taking out patents based on the indications given by these populations were obliged to take these rights into account[13]. The third principle concerns compensation. There are two aspects to this compensation: there is compensation on the markets – one can exchange pollution rights or buy rights saved up by others,

7. The idea that "sustainable development" is a useful oxymoron is well researched in La Revue Durable (2002) and in Gallardo (2008). See also Stengers (1999).

8. At the Johannesburg Summit, the firm BMW boasted that its cars were "sustainable" in an advert.

9. Zaccaï (2002 and 2009).

10. This (superb) quotation is taken from *http://www.wbcsd.org*, viewed on 19 December 2012.

11. These two paragraphs are derived from Maris (2012).

12. Ranganathan *et al.* (2008).

13. Aubertin *et al.* (2007).

for example – but there is also compensation which is claimed to be valid for nature: something that is destroyed in one place can be compensated by something that is created (or saved up) somewhere else. This may be valid for carbon measuring systems (atmospheric circulation spreads the CO_2) but this principle seems much more questionable for biodiversity protection.

Each of these three levels raises considerable problems. Obviously, all metrics, all measuring systems are simplifications and therefore they cannot avoid producing negative consequences. Virginie Maris expresses this well when she says that if we think simply in terms of carbon absorption, for example, and we plant eucalyptus forests (because they produce a lot of biomass) we will modify local ecosystems, erode the soil locally, wreck havoc on the water cycle and eventually jeopardise the region's environmentally sustainable development. The idea that something can be destroyed in one place provided that it is re-created in another place is both illusory and dangerous in environmental and sustainability terms.

In the context of total faith in market "efficiency", companies and their associations have taken a central role in the action to be taken (and States and large international organisations have given them this role). To ensure the "sustainable" management of companies, to perform balance sheet audits and overall results assessments, a whole range of systems and accounting mechanisms have been invented – guidelines, rules of good conduct, ways of recording data, ways of measuring their environmental footprint – and this phenomena affects green labels just as it does steel and cement companies. They all claim that the environment is a precious asset that should be cherished and they all publicly commit themselves to charters and programmes – the famous corporate social and environmental responsibility charters, or the French Grenelle Environment Forum which aimed to promote this oxymoron of sustainable development[14].

In all these initiatives, sincerity and good intentions rival the desire to be publicly irreproachable. An extreme sign of this is seen in the way consulting firms for businesses and major political parties in America have presented this issue since the late 1980s. Their advice, which is clearly cynical, is that the wishes of the people – who are in favour of sustainable development, who are both green and participative – should be taken into account and given a positive response, in the pitch at least. They advise their customers to insist upon the fact they want to save the planet; they tell them to take visible initiatives themselves and to strive to install "participative" policies – the bonus being that they will thus be able to better control social movements that can sometimes be unexpected. Because people's automatic confidence in organised science also seems to be waning, these reports also advise their customers, especially those likely to be the most affected by the changes, like oil companies or the Republican Party, to play upon this mistrust and refuse the conclusions of scientists when they threaten their interests. They advise them not to hesitate to ask for new studies and consultations with all the "stakeholders" – a classic delaying tactic – if the conclusions are not in line with their wishes[15].

An ideal that acts as a lead

However, sustainable development is not simply an ecological social-democratic societal project, a slogan which has become a flexible norm for 'correct speak' in the public sphere or a set of new practices for companies and markets. It is also a set of more or less coherent institutions and legal practices which have been gradually established over the years.

This institutionalisation is varied in nature, has many origins and produces effects which should be studied closely. These measures and practices have their original source in the militant action taken by associations and other NGOs that have developed since the 1950s and 1960s, and in the impact they have had on the public sphere – this is the oldest phenomenon and it remains essential and active today. Some of these institutions and practices have more direct origins in scientific

14. Daccache (2011).
15. Pestre (2008).

environments and their studies – but we know that the two worlds are not impermeable to each other: it was the coming together of scientists and associations which first revealed the need to invent sustainability. The IPCC is a typical example, but it is also the case with the protection of biodiversity or the development of notions of knowledge and indigenous peoples in the 1980s and which resulted from the meeting of field naturalists, environmentalist and developmentalist NGOs with representatives of local populations[16].

As we said, some of these achievements took form via United Nations' institutions but the European Commission also played an important role in promoting participation as a political norm and in raising environmental issues[17]. The reasons for its commitment are varied, although it is clear that its lack of legitimacy – it is not an elected body – plays an important role in its desire to be a great advocate of "participatory democracy" and the environment. It is because of this lack of legitimacy that it was able to be the spearhead of liberal policies in Europe, with the tacit approval of the States which had less elbow room – precisely because their leaders were accountable to their constituents. In other words, some of these reasons are entirely political (to impose liberal cultures and their modes of government) and others are related to their own specific fields of competence and modes of action (particularly with regards health or environmental regulations). Concerning the last point, we can mention Majone's theses which describe the policies followed by the European Commission as those of a "regulating" State rather than a sovereign State, of a State with little budget resources and which acts by enacting standards on the "quality" of products and production processes, of an institution whose aim is to increase regulation via markets to the detriment of more traditional political forms (representative political system) – of an institution which aims to reconfigure markets and "better" standardise them in economic and environmental terms[18]. We should also mention the institutions which rallied round later – the French State and its administration, for example – and which set up their own rules and practices, and their own media hype.

Assessing this institutionalisation in terms of the environment is complex. The results are limited but decisive – let me expand upon this paradox. In terms of "real" impacts, the result is often weak. With regards climate change, for example, the concrete results are limited, especially if one considers that the savings in the North are partly due to industrial delocalisation (but the industries pollute elsewhere) and even if for some countries like Germany, the results are not inexistent (but there was the integration of Eastern Germany and the drastic reduction of pollution generated by its former industries which were closed down). The last Copenhagen Summit is another sign of the difficulties encountered – as is the protection of biodiversity: undeniably, there have been some achievements here and there, in the management of water for example, or with regards Agenda 21 where local achievements are sometimes positive, but the underlying trends have not necessarily been reversed radically. Moreover, this is the very official conclusion drawn in the report commissioned by the UN Secretary-General for the twentieth anniversary of the Rio Summit which was submitted on 30 January 2012. Set up just like the Brundtland Commission, the High-Level Panel on Global Sustainability brings together a large number of ministers – and includes Mrs Brundtland herself. This committee's conclusions are disturbing and I shall simply give two examples of this. According to this group, annual emissions of carbon increased by 38 % worldwide between 1990 and 2009, and 85 % of fish stocks are now over-exploited[19].

The reasons for these limited effects are well known. Without once again bringing up problems specific to market frameworks, we can first say that since there are no longer any obligations – they are usually "incentive policies" – and since financial compensation can be had by those who do not comply with the rules, results are sometimes difficult to achieve. It should also be noted that, as in the fight for parity between women and men in politics, the fight for environmental and social

16. Boisvert (2005), Merson (2000).

17. It was officially instituted as a rule of good governance by the Commission of the European Communities' White Paper (2001), a paper that researchers in social sciences had been preparing since the mid 1990s.

18. Majone (1995, 1996), Barry (2001).

19. On the United Nations website, *http://www.un.org/wcm/content/site/climatechange/pages/gsp*

Drawing by Robert Rousso *in le Courrier de l'environnement de l'INRA* nº 44.

sustainability is a never-ending battle. In the latter case, it is against the idea that politics is a matter for men; with regards the environment, it is against the logics of habit, the logics of low-cost production and consumption. As Dasgupta wrote in the past, economic players (and many others) would prefer environmental resources to remain free and, without the enactment of binding rules that only state players could take, there is little reason to economise these resources[20]. Therefore, it is inevitable that there will regularly be sudden steps backwards in the future – the case of the decrees on the conclusions of the French Grenelle Environment Forum illustrates this well.

However, the impact is essential in another register – because the standards and values supported by these institutions shape and constrain, via the public sphere, individuals, companies, States and social bodies. With regards political parity, to pursue my analogy, the change of category and framework of questions – moving from equality to parity – has admittedly masked problems that were formerly well identified – for example the social connotations of equality. But in doing so, it has allowed the emergence of common ground and allowed right-wing women to exchange ideas with left-wing women in Parliament and this has led to new solutions being put into law[21].

Likewise, the vocabulary of sustainable development and the forms of action implemented by institutions which promote it are not without consequences. These ways of regulating the world – repeating the need for sustainable development on the one hand and agreements like the Aarhus Convention and Cartagena Protocol on the other hand – produce effects on a daily basis. These institutions constantly reactivate the relevance of these issues within the public sphere; they help prevent them from becoming "invisible" again and prevent people from ignoring them too easily. They are also the occasion for legal or administrative recourse, which contesters can always pursue; they are resources for public actions – and courts give rulings.

Thanks to this institutionalisation, inadmissibility and the onus of proof often change sides. For example, once it is publicly recognised that development must be sustainable, it is up to those accused of not adhering to this principle to justify their act or their failure to act – and this is why "sustainable development" is an efficient oxymoron. Admittedly, concrete achievements may completely differ from words, but having to express ones' concerns and repeat ones' commitments does not fail to have an effect on consciousness and standards – and on players' practices. Indeed, picking up on an example already discussed, the representation of relations between humans and the environment in terms of "ecological services" (or eco-system services) is highly problematic in philosophical, political and environmental terms, we said it, but it helps keep the issue of the environment in the spotlights for all players[22].

Therefore, these institutions have the advantage of being the incarnation of set of constraints which weigh down on politics, industry and social worlds – even if the framework for everything is flexible, that some solutions have dubious consequences and that, in practice, there are many loopholes. And there is a positive aspect even when no obligation is imposed and the commitment is voluntary. This obliges players to negotiate and makes it difficult for them to act without showing good will and cooperation – and it enables the most convinced players to constantly raise the issue.

A dangerous ideal that should be abandoned

Finally, there is a last way of describing sustainable development: many people believe that it is a hit target, a conception of the world that cannot be attacked head-on because it has an attractive and affective aura, but that has to be undermined from the inside and as far as possible refused because it is a bad policy. To illustrate these views, I shall present the arguments found on the websites of American conservative *think tanks* concerning the Kyoto Protocol the day after the Copenhagen

20. Dasgupta (2000).
21. Lépinard (2007).
22. Ranganathan *et al.* (2008).

Summit in December 2009. Based on the texts from the two foundations Heritage and Enterprise, here are the statements found, and on which I shall make comments[23].

(1) According to recent data, global warming has decreased over the past decade; in any case, scientific climate analysis is not always of excellent quality and lacks transparency – a line of argument which has become more widespread since November 2009 and which involves attacking the solidity of statements by the IPCC and showing that its science is not *waterproof*. This is a classic tactic – studies on science have shown that it is always possible to undermine the solidity of any argument by targeting the particular character of its simplifications, which are inevitable. This tactic is now being used against the IPCC by those who do not want to bow to the constraints that would result from its reports or who consider that these reports have become the new *doxa* that modern-day "Galileos" have a duty to criticize (this is the case for quite a large number of scientists).

(2) Second argument: the Kyoto Protocol, as it exists, is a failure, and does not lead to the reduction in carbon emissions anticipated; articles cite the case of Canada, and even Japan, which do not perform as well as the United States – although the latter are not party to the protocol and they allow markets to act without reducing growth. The line of argument here is that voluntary commitments only commit those who believe in them and a little less naivety is a common good that should be spread more widely.

(3) The third criticism is aimed at the heart of the matter, at the foundations of any social-democratic approach, *i.e.* its commitment to sharing, its commitment to civil justice and equity. The argument takes several forms, particularly the refusal to consider past responsibilities – a line of argument which took on its contemporary forms with the conservative *think tanks* in the United States in the 1990s and during the Bush era. Counter to the ideals of advocates of the Kyoto Protocol, they reasserted the principles of hard-line *Realpolitik* – the fact that we are at war, even if this is an economic war. This ideology of a necessary war, notably a preventive war (because it is not simply an economic war) became a dogma between 2001 and 2008. It is still present today and its implications, whereby there is no need for us to repent, can be found in attenuated forms in France, in the views expressed by President Sarkozy. Therefore, the United States does not need to act like a victim, the North does not need to pay "eco-compensation" – contrary to the "activists'" demands. The conclusion is that China or India should not be treated any differently from the United States and, therefore, they should pay just like the others do, in proportion to their current emissions.

(4) The fourth argument is based on an assessment (implicit but ideologically effective) of development aid and the pernicious effects it has sometimes (often? always?) produced in the past. Paying for the development of others is not a satisfactory development policy and free markets are much more effective – as proved by the development of many countries in the South since the liberalisation in the 1980s. Moreover, the North should not transfer its technologies without some kind of compensation, especially with countries undergoing a development boom like China. These transfers should be left to the initiative of economic players and markets – unless we want to give up our most basic rights (ownership, for example) or commit suicide!

(5) Another argument: the cost of agreements like the Kyoto Protocol is too high for the (American) economy. Anyway, the temperature improvement they achieve is marginal compared to the cost, and other solutions, *i.e.* technical solutions, will be found. In this case, the line of thought is that after the period of indoctrination and militant agitation, after the phase of activism by radical ecologists and irresponsible people, but also after the era of generous souls promoting coordinated, equitable and sustainable development, we will finally enter a more reasonable era of green technologies which will radically change the order of things. And in this case, markets are the best tools we have at our disposal. In any case – and of course this principle cannot be contested – it is up to the

23. The Heritage Foundation, *http://www.heritage.org*; American Enterprise Institute for Public Policy Research, *http://www.aei.org/home*

markets to solve the climate issue, as it does with all the other issues. If there really is an environmental issue, correctives will be found via markets, at a lower cost.

(6) The sixth type of argument concerns the essence of international relations, the basis of "real" geopolitics and the nature of States' relations. There are two aspects to this point. Firstly, it concerns the central role of States, the fact that they are the sovereign basis for all regulations and that the balance of power between countries is at the heart of international relations. Secondly, it concerns the fact that no "higher" authority can come between them and the fact that multi-lateralism is a danger, a myth and political naivety. Multilateral agreements, especially if they are binding, are an infringement of sovereignty – of the United States' sovereignty – and are not feasible solutions. Moreover, there is obviously no reason why the United Nations should be trusted to manage funds – especially funds from American taxpayers. Besides, the United Nations have often shown that they are vulnerable to embezzlement and the worst possible despots.

These *Realpolitik* considerations are in great part responsible for the failure of the Copenhagen Summit – and they relate to the second major transformation of the past two decades, side by side with the one which sought to establish negotiated and shared governance and sustainable development. In other words: the return of militant economic liberalism coupled with a conservative revolution defending the inevitability of the clash of civilisations.

There are several facets to the neoliberal philosophy. The one that concerns us here, expounded by Hayek in his book *The Road to Serfdom*, considers that any kind of anticipation and planning, even if it is indicative, is like a *hubris* and should be abandoned[24]. The idea that the human mind can understand the complexity of the economic and social world – not to mention the complexity of its interaction with the Earth system – and that it can conceive efficient collective policies is just an illusion. Humans are incapable of this, and any action they take in this direction is likely to cause more damage than good – because the human mind is too limited and only markets are able to calculate efficiently. Therefore, putting this into the hands of an international bureaucracy that claims to be competent but which in fact is disconnected from economic and political realities, and thus disrupting the natural and efficient action of the markets, is a heresy committed by sustainable development and its related institutions – as it was previously by the social-democratic dream and the unjustified regulatory role it gave to the State. Indeed, these declarations can be interpreted as ways of defending well-understood interests but they illustrate deep-rooted convictions adopted by large numbers of people in North America and throughout the world.

These convictions are so deep-rooted that they have joined up with a conservative revolution which has brought forth, as if it was a rule of life, a sort of new widespread war of interests and cultures renamed war of civilisations. It has led to the stigmatisation of others (the Evil Empire) and to the assertion that it would be futile to enter into discussions with such people. This conservative revolution leads to withdrawal and to another range of essential values. It discourages us from trusting others – an exact opposite of the idea of sustainable development which is consciously controlled and constructed in common and through discussion[25].

Chronologically, this phenomenon began to appear at the same time as the liberal revolution initiated by Pinochet, Thatcher and Reagan – which of course is also a revolution in values – but it only took its new course, particularly for international relations, after the fall of the Berlin Wall. Those who have been called neo-conservatives started their campaigns at the beginning of the 1990s. Determined to ensure that the United States play a unique role on the new geopolitical stage, the role of a security guard not bound by common rules, they refused any process of shared governance which would involve them. They reasserted the supremacy of States and their interests, with the

24. The question of the limits of the human mind, even collective, when it seeks to understand the world and define efficient policies, is real. But this in no way implies that we cannot or must not do anything consciously and deliberately. Even supposing that markets could be efficient calculators, the values of "efficiency" that they carry do not exhaust the things that human societies may wish to achieve. Other regulatory methods need to be mobilised and Hayek's assertions should be taken for what they really are: a political programme.

25. On the war of civilisations, Huntington (1997); see also Pestre (2009).

primary goal of reorganising the Middle East which was asserted in the mid 1990s. Coming into power in 2000 with the election of G.W. Bush, but accelerated by the events of 9/11, these neoconservatives supported a cultural revolution from deep within the country and entered into the hot war in Afghanistan and Iraq and then into the war on terrorism. The value that then emerged as a central value was no longer one of dialogue but one of security.

In my opinion, it is the existence of these two conflicting societal projects – the sustainable development project and the conservative and neoliberal project, but above all *their head-on encounter at a time when concrete commitments had to be made*, which is the key to the failure of the Copenhagen Summit. I think that the result of December 2009 reveals a situation which was present before but not yet deployed, and it should lead Europe, which has placed sustainable development at the heart of its actions, to reconsider its *wishful thinking* whereby it is impossible that its project is not the obvious solution shared by one and all. This project does not lack pertinence given the situation – quite the contrary; efforts to make this societal project succeed should not be abandoned; I believe it is a just project. But the job is going to be more difficult than expected and we must act with full knowledge of the facts because it is not going to be a smooth ride to "suitable governance". Real interests, different logics and other societal projects exist and they have many partisans. Admittedly, the project of sustainable development enjoys a positive *a priori* in some segments of the world's populations, and this may prove decisive in the future, but its assumptions are not universally accepted.

Despite our commitment to sustainable development, to the sharing of knowledge and to collective decision making methods, despite the worthiness of these ideals which may be very deep-seated within us, we must realise that the world is such that this belief is not shared and that, to the contrary, it will be fought against by powerful people. Could this lead to a catastrophe? This is possible, because civilisations are mortal and human collectives are capable of destroying themselves[26]. Therefore, it is even more essential that we try to reverse this outcome. This is why we have to pick up the reflexion again, not on the basis of a simple idea, but on the basis of the variety of issues, the complexity of situations, the variety of possible solutions and the undesirable effects they may produce – and "cold" analysis of what may happen.

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Theories of collective action and common goods

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Collective action is an area of knowledge which, stemming from political and management sciences, has increasingly entered the economic and social sciences since Rio 92. Marked by the Nobel Prize in Economics awarded to Elinor Ostrom in 2009, collective action has fuelled research into the management of non-private goods, public goods and common goods.

Public goods, common goods in economics

– a *public* good is a good which is non-rival and from whose use no one can be excluded: the use of a public good by one individual does not reduce the possibilities of use by others.
– a *common* good – or *common pool resource* – is a good whose use by some limits the possibilities of use by others. It is referred to as "rival". It is also possible to exclude users. Finally, a common pool resource is liable to degradation, and even disappearance, through use. This applies to the extinction of marine species from overfishing.

The research of the scientific community working on common pool resource management takes as its starting point Mancur Olson's "logic of collective action" (1965). Olson frames the issue of collective action in terms of individual choices, of which collective choice is the sum: his approach is one of methodological individualism, and game theory can be employed. Elinor Ostrom's work is initially in line with this approach, as shown by her founding work *Governing the Commons*. But in that same book, Ostrom goes on to discover how collective action is about more than just individual cost-benefit calculations, and how cooperation tends to win out where theory would have it fail. The paradigmatic prisoner's dilemma[1] is not consistent with a world in which the actors discuss amongst themselves.

The development of research on common pool resources has been accompanied by epistemological and methodological shifts in synchrony with the evolution of modelling tools, in particular computer-modelling (Jansen *et al.*, 2011; Le Page *et al.*, 2012). In France, an interdisciplinary team, Cirad-Green, was set up in 1993, with conceptual foundations akin to those of Ostrom's team. It was equipped with a multi-agent simulation (MAS) platform called Cormas, enabling the simulation of interaction dynamics between "objects" or "agents" in the information technology sense, which could be humans, animals or plants, or even watercourses or roads, complete with knowledge and rules[2]. The team then developed role-playing games linked to the simulations, with the following underlying research question: how do individuals exploiting common pool resources draw up and develop rules? This is a question which cannot be posed by experimental games in which the players follow predetermined protocols. Ongoing scientific relations since the late 1980s have seen these initiatives cross the Atlantic, contributing to a new dynamic centred on one essential question: What is trust? How is it built? *Working Together* (Poteete *et al.*, 2010) reviews the development of issues and methods in the sphere of collective action, focusing on the emergence of effective, adaptive collective rules for the exploitation of renewable resources and common goods.

1. The *prisoner's dilemma* is an example of game theory: cooperation is never chosen by a rational player in situations where it would be in the interests of two players to cooperate, but where the incentives to betray the other are strong, and where the game is played only once. The problem lies in reconciling the quest for the individual and collective interest.
2. *http://cormas.cirad.fr*

Drawing by Robert Rousso *in le Courrier de l'environnement de l'INRA* nº 36.

Collective action in the field of common goods has played an important role in understanding the interactions between social and ecological dynamics, and was key to the founding of the Resilience Alliance[3] and the creation of the *Ecology and Society* journal (*http://www.ecologyandsociety.org*). 1989 saw the founding of the International Association for the Study of Common Property (IASCP). Its first conference was held in Winnipeg (Canada) in 1991, with over 300 participants (including two French), just one year after the publication of Elinor Ostrom's seminal work and two years after the publication, in *Nature*, of "The benefits of the commons" by Berkes *et al.* (1989). The latter article was an all-out criticism of Garret Hardin's article published in *Nature* in 1968: "The Tragedy of the Commons". The "tragedy of the commons", which rapidly became a paradigm, had legitimated the assertion by economists, international (World Bank, FAO) and bilateral agencies that the privatisation of resources and spaces was a panacea for development. The result had been ecological and social catastrophes in countries of nomadic pastoralism, among the Maasai of Tanzania (Rutten, 1992) and the Fula of Senegal. Beginning in 1996, Bousquet *et al.* used simulations to show how, in repeated, spatialised prisoner's dilemma situations, neither cooperation nor betrayal won the day (Bousquet *et al.*, 1996). They found results akin to those of Novak *et al.* (1995) on the origins of cooperation in nature.

Theories of collective action have tackled a wide range of fields: common goods and common pool resources, dynamics of social networks (internet) (Hess, 2008), intellectual property and the emergence of "global commons" (open-source software) and "creative commons", along with shared gardens, collaborative plant selection and the management of radio and television channels. They are increasingly incorporated in research on the forms of social and solidarity economy.

Researchers note that the size of the commons is the main difficulty encountered by collective action. They observe how local groups are progressively being set up, whose interconnection better ensures the viability of the whole on a large scale. This applies to Facebook, LinkedIn and other social networks, where restricted groups of "friends" or "colleagues" are set up, which together form the larger network.

3. The Resilience Alliance is an international research network that is a world reference in complex systems modelling and the resilience of social-ecological systems. It publishes the journal *Ecology and Society*.

One of the major conclusions of more than 30 years of research and hundreds of doctorates is summarised by Elinor Ostrom as follows: groups of users are more effective in managing common pool resources than the State or the market. At a time when centralised modes of coordination have been overtaken by coordination in networks, these results are encouraging in that they reaffirm the primacy of social ties over any form of technocratic "recipe". Marginal until Ostrom's Nobel Prize, that research is becoming increasingly wide-reaching due to the world economic crisis and the difficulties of the classic shareholder model in the face of cooperative/mutualist models around the world. At the heart of the demonstration lies trust: what is it and how does it emerge? Back in the 1990s, some economists had addressed trade from this angle (Rouchier, 2000), and Alan Kirman (Kirman and Vriend, 2000) explored its workings in the Marseilles fish market.

The reasons why the conventional theory of collective choices is inadequate to the understanding of common goods are summarised by Ostrom (2011). Their authors, such as Olson, Hardin and others (in France, for example, Crozier and Friedberg, 1981), assume that individuals seek to maximise their profits in the short term. They predict that no one will cooperate for the collective good in dilemma situations: "going it alone" or overexploitation, then, are seen as dominant strategies in the sense of game theory. This standard theory is widely taught in universities.

To improve the results of this conventional theory, it is assumed that new rules must be imposed from the outside, by the State or the private owner. The standard theory states that participants are unable to self-organise. Scientists are therefore asked to develop models aimed at coming up with optimum solutions.

These theories, as we have said, are confirmed only in experiments where there is no communication between the actors. In experiments where there is communication, high levels of collective action can be observed.

To develop the conventional theory into a behaviouralist theory means making the following assumptions:

– individuals have good intentions but limited rationality;

– individuals have the capacity to learn, in particular social rules;

– individuals learn the standards and preferences of others.

Trust results from an assurance of reciprocity in the action or commitment. The resulting cooperation adds to the mutual benefits. This is illustrated in the figure 1.

Institutions are governed by the same logic, insofar as they are defined as agreements between at least two individuals or groups imposing themselves on more than just those two individuals or groups. The viability of institutions depends on the trust the actors have in them and on their ability

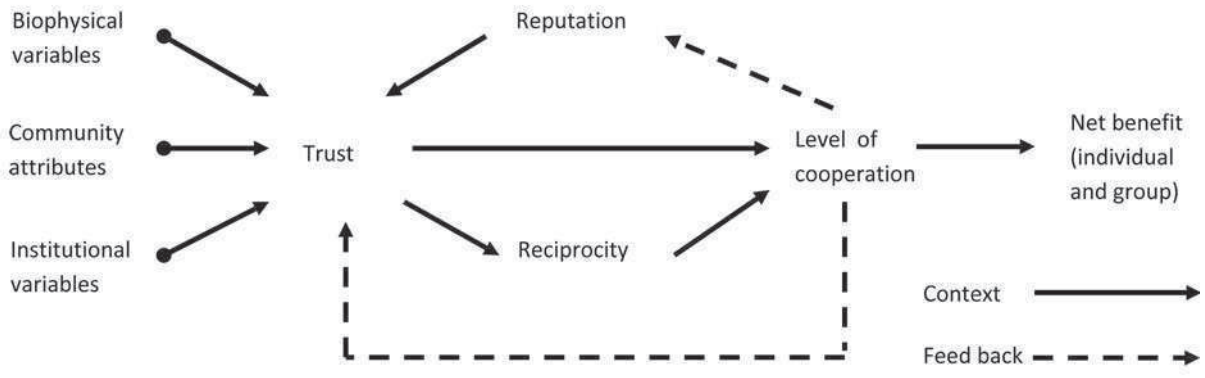

Figure 1. Context and feed back in repeated social dilemnas. *Source:* adapted from Orstrom and Walker (2003).

to preserve that trust. The loss of trust in the institution of marriage, for example, is in large part responsible for its erosion. The office of president of a nation, a major institution, loses its substance in the event of loss of trust, and the constitution (another major institution) is there to prevent the loss of trust in a president from becoming a loss of trust in the presidential institution.

It is understandable why research on common goods, forms of ownership and trust are of great importance to the social economy: the journal *Revue Internationale de l'Economie Sociale* saw Elinor Ostrom's Nobel Prize as "a distinguished testament to the topicality of the social economy. [...] This prize comes at a time when, throughout the world, people are organising themselves to recover common goods which have been alienated (*e.g.* mineral resources exploited by multinationals).

One of Ostrom's decisive contributions is precisely her showing that, far from being resources, commons are a form of collective property: there are no commons without community. In other words: nor can there exist a social economy enterprise without a group of shareholders." (Draperi, 2009) Although the author strays somewhat from Ostrom's conceptual framework, he nonetheless clearly illustrates the overlap between research on common goods and research on the social economy.

That overlap is of major importance, in the run-up to the Rio + 20 summit, in a context of deep global economic crisis, which is seeing a challenge to the belief in an omnipotent, omniscient, self-regulating market. In this context of growing instability, the forms of organisation based on shareholders and profit maximisation are damaged. Meanwhile, the forms of organisation specific to the social economy – cooperatives, mutuals, associations – tend to stand up less poorly to the crisis. One top executive of a leading insurance company said he saw the "unfair" (sic!) competition of mutuals as the cause of part of his company's difficulties. He described that competition as "unfair" because, since they did not have to pay shareholders, mutuals could charge lower prices! Organising users in cooperative/mutualist forms of enterprise is certainly less costly, more stable and more focused on solidarity than the capitalist form, which besides substitutes solidarity for charity, in the fashion of certain large fortunes. Rio 1992 called for intergenerational solidarity; the social economy calls for immediate solidarity, and for actors to organise themselves on a voluntary, collaborative basis. In that solidarity, advances in the theories of collective action and common goods will be sure to find one of their *raisons d'être*.

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Opening up French law to public participation[1]

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The Earth Summit held in Rio de Janeiro in June 1992 was of capital importance as far as public participation in environmental decision-making processes is concerned. The principles adopted in Rio soon found an echo in Community law, and then in French law.

A few months away from Rio+20, where a new chapter on public participation will perhaps be written, I felt it would be useful to look at the law governing that participation.

In international law

International law was quick to give a great deal of importance to taking account of the interests of stakeholders, then citizens.

Premises

The Stockholm Declaration of 16 June 1972[2] laid the foundations of the concept of sustainable development[3], leading to corporate social responsibility which, according to the legal doctrine, in turn led to the legal notion of the stakeholder[4]. It affirmed man's right to an environment of quality, stating by way of such principle that the public had for duty to take responsibility in safeguarding and improving the quality of the said environment[5].

In 1982, the World Charter for Nature[6] stated that all persons should have the opportunity to participate, individually or with others, in the formulation of decisions of direct concern with their environment (paragraph 23).

In Europe, Resolution 171 (1986)[7] on "Region, environment and participation" contains provisions on public participation in the environmental decision-making process. It calls in particular on local and regional authorities to "inform citizens clearly and precisely about any measure taken or to be taken concerning the environment, given the direct impact of these issues on their quality of life".

1. Based on a placement report ("rapport de stage") as part of a Master 2 in Public Law, University of Maine (France), 111 pages.

2. Resulting from the United Nations Conference on the Human Environment, 5 to 16 June 1972.

3. On the difficulties in determining the term "sustainable", see Chantal Cans, 'Le développement durable en droit interne: apparence du droit et droit des apparences', *AJDA*, 2003, p. 210.

4. Marianne Moliner-Dubost, 'Démocratie environnementale et participation des citoyens', *AJDA*, 2011, p. 259.

5. Principles 1 to 19.

6. Resolution 37/7, adopted by the UN General Assembly on 28 October 1982.

7. Adopted on 14 October 1986 by the Standing Conference of Local and Regional Authorities of Europe, under the auspices of the Council of Europe.

Next came the Rio Declaration[8] which, in addition to establishing up Agenda 21[9], would formalise these declarations. In Principles 1 to 10, it states that "[h]umans beings [...] are entitled to a healthy and productive life in harmony with nature" and specifies that, "[a]t national level, each individual shall have appropriate access to information concerning the environment [...] and the opportunity to participate in decision-making processes".

Principle 10 also clearly states that "[e]nvironmental issues are best handled with participation of all concerned citizens". That principle is reiterated in Chapter 28 of Agenda 21.

Although having no legal force, Agenda 21 states that "[a]s the level of governance closest to the people, [local authorities] play a vital role in educating, mobilizing and responding to the public to promote sustainable development". According to the legal doctrine, local authorities are essential "to the formulation of the most appropriate strategies to cater more specifically for their sustainable development needs"[10].

The Aarhus Convention

The Aarhus Convention of 25 June 1998 was drawn up in the framework of the United Nations Economic Commission for Europe (UNECE), a multilateral platform of 56 States of from North America, Europe and Central Asia, whose role is to implement at regional level the results of UN Summits and World Conferences.œ

The Convention, with its 22 articles, provides in its preamble that "citizens must have access to information, be entitled to participate in decision-making and have access to justice in environmental matters"[11]. In Article 6(2), it specifies that "[t]he public concerned shall be informed, either by public notice or individually as appropriate, early in an environmental decision-making procedure, and in an adequate, timely and effective manner".

It also provides that "non-governmental organizations promoting environmental protection and meeting any requirements under national law shall be deemed to have an interest" (in acting). In force since 30 October 2001, the Aarhus Convention is therefore based on a fundamental principle whereby the more citizens' awareness is increased, the more their involvement in decision-making processes will be. And, in the eyes of its drafters and signatories, by giving people access to all the information concerning environmental issues, will it allow to improve environmental protection.

The first section of the Convention sets out relatively specific rights and obligations concerning access to information, in particular the time-limit within which the public authorities must notify their reasons for refusing access to certain types of information[12].

The second section concerns public participation in the decision-making process. According to the Convention and its different annexes, that participation must be ensured in the authorisation procedure for certain specific activities (involving considerable risks to the environment and citizens). In the context of that authorisation procedure, account must be taken of public participation in the final decision to authorise the activity.

The Convention also invites the parties to encourage public participation in the preparation of policies related to the environment, as well as standards and legislation that are likely to have a significant impact on the environment.

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8. Resulting from the Earth Summit, 3 to 14 June 1992.

9. Action plan for the XXIst century which sets out more than 2 500 recommendations concerning the implementation of its 27 principles. The signatory States to the Rio Convention undertake to implement it at national and local level. All local and regional authorities of those States are required to implement Agenda 21 at their level, incorporating sustainable development principles by means of a public consultation mechanism.

10. Marie-José Del Rey, 'Agenda 21: mode d'emploi', *AJ Collectivités Territoriales*, 2011, p. 230.

11. Aarhus Convention, recital 8, p. 2.

12. Three circumstances justify a refusal: the information is unavailable (either physically or due to specific legislation, for example defence secrecy, industrial confidentiality or intellectual property); the question/request for information is not relevant; the request relates to preparatory documents.

Drawing by Robert Rousso *in le Courrier de l'environnement de l'INRA* nº 27.

In European law

The European Community took the appropriate measures in order to ensure the effective implementation of the Aarhus Convention. Directive 2003/35/EC of 2003 would reflect this perspective, recalling Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment: "The public concerned shall be given early and effective opportunities to participate in the environmental decision-making procedures" (2003 Directive), at a time "when all options are open and effective public participation can take place" (1985 Directive).

As a consequence the 2003 Directive would thus implement at Community level the first section of the Aarhus Convention, concerning public access to information[13]. Although the second section of the Convention, concerning public participation in environmental procedures, was transposed by Directive 2003/35/EC, a 2005 Decision would go on to improve Member States' environmental legislation through the approval of that same Convention, taking up and adapting its provisions as part of Community law[14].

Lastly, a Regulation adopted in 2006 sought to ensure the application of the provisions and principles of the Convention to Community institutions and bodies[15].

To conclude, it is worth noting that, in two decisions, Community judges would first recognise and confirm the indirect enforceability of the Aarhus Convention[16], then require Member States to implement procedures for the environmental assessment of projects and for public participation[17].

In French law

The French legal system includes various mechanisms for participation, concertation and consultation, such as the public enquiry – the oldest form of participation, introduced in 1810, whose original purpose was to ensure the protection of citizens' property rights in expropriation proceedings – and the public debate, under the auspices of the National Commission for Public Debate (CNDP), provided for by Law nº 95-101 of 2 February 1995 on environmental protection, which applies to large-scale operations of national interest. Mention can also be made of the concertation mechanism, codified in Articles L.122-1-1, L.123-3 and L.300-2 of the Urban Planning Code (Code de l'Urbanisme), concerning the formulation of urban-planning documents and the execution of development operations.

The changes made to these three mechanisms are a clear reflection of developments of the participation in French law, dependent on both national and international political aspirations. We can attempt to measure those developments on the basis of two of the founding principles of the Aarhus Convention: access to information and participation (the third being access to justice).

The public enquiry: a distant predecessor

Since its creation, the public enquiry has been altered on a number of occasions. In 1983, even before the Aarhus Convention, the Law on the Democratisation of Public Enquiries and Environmental Protection[18] was passed, which turned the public enquiry into a procedure aimed at informing and collecting the opinions of citizens, able to take in better account of the general public interest.

13. Directive 2003/4/EC of 28 January 2003 on public access to environmental information.

14. Council Decision of 17 February 2005 on the conclusion, on behalf of the European Community, of the Convention on access to information, public participation in decision-making and access to justice in environmental matters (2005/370/EC). By this Decision, the Aarhus Convention, signed by the European Community and its Member States in 1998, was approved on behalf of the Community.

15. Regulation (EC) nº 1367/2006 of 6 September 2006.

16. European Court of Human Rights, Application nº 46117/99, 10 November 2004, Taskin v. Turkey.

17. European Court of Human Rights, Application nº 67021/01, 27 January 2009, Tatar v. Romania.

18. Law nº 83-630 of 12 July 1983.

Public enquiries can involve a wide range of projects; the list is not restrictive, but the projects must be likely to have an impact on the environment and/or the quality of life of residents. Projects may come from the State, local or regional authorities, private companies or public corporations. Public enquiries are conducted by an investigating commissioner (commissaire-enquêteur), appointed by the president of the Administrative Court. In the case of particularly complex, weighty or sensitive projects, the Court may appoint a commission of enquiry (commission d'enquête), composed of an odd number of commissioners.

It is a procedure in which all citizens may express their interest, without restriction. Anyone may obtain information, express their views, make an assessment, issue criticisms or put forward suggestions or alternative proposals concerning the project.

To obtain information, the public has access to the project documents "throughout the course of the public enquiry", as confirmed by the Administrative Court[19]. To express its views, it has two main channels: by submitting its observations in writing to the investigating commissioner or by entering those observations in a register made available to the public at all the locations visited by the commissioner.

Public enquiries were not fundamentally transformed in 2010. Although changes were made by the Law of 12 July 2010 (the National Environment Commitment, or ENE, also known as Grenelle 2), those changes concerned only the consequences of public enquiries, and in particular changes to projects[20].

These legislative amendments could be seen as positive, both in terms of informing the public, since the project documents are available to all, and in terms of participation, since anyone may give their views. But public enquiries continue to suffer from major handicaps.

First of all, they happen far too late in the decision-making process, when the project is a *fait accompli* (so that, to some, they are merely a process for legitimating a project), in blatant contradiction to the recommendations of the Aarhus Convention.

Second, although the public is able to give its views on the project submitted to it, the competent authority is under no obligation to take those views into account, even when the investigating commissioner issues an unfavourable opinion. Thus, the Administrative Court has never failed to recall, for example in relation to Local Urban Development Plans (PLUs), that "the legality of the challenged decision cannot be affected either by the fact that the change adopted includes provisions criticised by a large number of local residents or environmental specialists during the enquiry, or by the fact that the municipal council did not take account of the unfavourable opinion of the investigating commissioner concerning rectifying the challenged regulation, since that opinion was not binding"[21].

The Barnier Law[22] admittedly altered the consequences of unfavourable conclusions from the investigating commissioners in public enquiries, by reviving the deliberative bodies, stating that "any project of a local or regional authority or group of local or regional authorities which has given rise to unfavourable conclusions from the investigating commissioner or the commission of enquiry must be discussed by the deliberative body of the authority or group of authorities concerned". But it was very much a marginal alteration.

19. See, to this effect, Strasbourg Administrative Court, 19 June 1990, Association Lindenkuppel c/ Préfet du Rhin, RJE 1991, n° 2 p. 221.

20. In the event of proposals being accepted, Article L.123-14 of the Environment Code (Code de l'Environnement) provides, in substance, that if the contracting authority wishes to make major (substantial) changes to the project during the public enquiry, the competent authority may suspend that enquiry for up to six months. This period of time is to allow for the necessary changes to be made, and the project may even undergo new environmental assessments. The public is then notified of the changes made, and the enquiry period is then extended for at least a further thirty days.

21. Montpellier Administrative Court, 27 May 1992, Association Charles Flahault pour l'Étude et la Défense de l'Environnement des Pyrénées-Orientales, Application n° 89348.

22. Law n° 95-101 of 2 February 1995.

Concertation: a shaky mechanism

Stemming from an urban-planning law dating back from more than thirty years, the concertation procedure is itself undeniably dated and is no longer a genuine mechanism of public participation, but merely an obsolete apparatus, at best a supplementary procedure in view of the public debate and public enquiry, although it does address a very specific part of public participation at local level.

It was incorporated into the Urban Planning Code in 1985 by a law of the same year[23], finding a place in that code, at Article L.300-2, among other provisions governing public participation in local authority decisions in respect of planning and the environment. It concerns any amendment or revision of an urban-planning document opening up to a future urban-development area, the creation of a concerted development area or any planning operation carried out by the local authority (in the event of a substantial change to quality of life or economic activity in the local area).

The legislator formulated this concertation as an internal process, governed by decentralised local authorities alone and tending to reasonably limit the constraints weighing upon them in the context of public participation, rather than as the recognition of the public's genuine right to participate in the formulation of planning decisions at local level. It is a minimal recognition of the public's capacity to participate in decision-making processes concerning issues that could affect their quality of life.

In 2000, a law[24] would extend the concertation procedure to include "any formulation or revision of Territorial Cohesion Plans [SCoTs] or Local Urban Development Plans [PLUs]", thereby seeking to transpose as closely as possible the provisions of the Aarhus Convention concerning public participation.

A law of 2003[25] would go on, in Articles 6 and 7[26], to extend the sphere of application of concertation to include all planning documents having an influence on the development of urbanisation.

However, the concertation procedure underwent a twofold neutralisation, first through a curb on any expansion of its scope of application, then through the restriction of its legal significance.

Thus the list of operations concerned by concertation was restricted, in particular through the establishment of thresholds (financial and based on area). The reason for that restriction can be found in the sphere of parliamentary debate: in all likelihood, the Government and Parliament agreed to reduce the risk of litigations which would arise from too lax a procedure in favour of stakeholders.

Second, the law of 2003 weakened the significance of concertation, stipulating that "urban-planning documents and operations [...] shall not be unlawful solely on the basis of defects likely to undermine the concertation, if the procedures set out in the stipulated decision [...] have been fulfilled"[27]. The only circumstances in which concertation might lead to a project being legally challenged are those in which that concertation was not organised despite being required by law, or else was replaced by a pretence of concertation[28].

However, from the standpoint of stakeholders' views being taken into account, however, concertation is an essential step in relations between the authorities and the public when projects are formulated at local level. A coordination mechanism, its rules need to be clarified if it is to find

23. Law nº 85-729 of 18 July 1985 on the definition and implementation of planning principles.

24. Law nº 2000-1208 of 13 December 2000 on solidarity and urban renewal.

25. Law nº 2003-699 of 30 July 2003 on the prevention of technological and natural disasters and compensation for damage, known as the "Bachelot Law".

26. Codified in Articles L.515-22 and L.526-3 of the Environment Code.

27. Urban Planning Code, Article L.300-2c.

28. See, to this effect, Conseil d'État, 10 May 1996, nº 155169, Commune de Saint-Jorioz v. SCI La Tuilerie: the Administrative Court sanctioned a mere exposition, lasting a short time, organised during the public enquiry, together with a meeting with an approved environmental protection organisation, as constituting a concertation. In another example, the Land Use Plan was simply displayed at the town hall, with no explanation, even though the Land Use Plan was subject to a prior application: Poitiers Administrative Court, 25 June 1998, M. R. Gosselin v. Commune de Bignoux, AFDUH, 1999, p. 162, confirmed by the Bordeaux Administrative Appeal Court, nº 98BX01499, 6 December 2001, Commune de Bignoux.

its true significance, drawing more strictly on the notion of concertation used in Community and international law.

Since January 2012, Article L.300-2 has been under revision by order (a procedure provided for by the Law of 10 July 2010, Grenelle 2)[29]. It is the Conseil d'État (Council of State) which must determine by decree, no later than 1 January 2013, the date of entry into force of the new provisions of that article, the current ones continuing to apply until then.

Although, at present, one cannot predict what the substance of that reform will be, it is worth noting that Article 6 addresses concertation, giving it a broader sense and being more specific about how it is organised. Might this order pave the way for greater account to be taken of the views of the public?

The public debate: a paragon of virtue in terms of information and participation

The public debate was created by Law nº 95-101 of 2 February 1995 (the Barnier Law) which, in Article 2, provides that a public debate may be organised for different large-scale public planning operations of national interest of the State, local or regional authorities or their subdivisions. Those projects must be of major socioeconomic importance and/or have a significant impact on the environment.

The debate is conducted by the Commission nationale du débat public (National Commission for Public Debate, or CNDP) in the conditions laid down by Decree nº 96-388 of 10 May 1996 on the consultation of the public and organisations prior to planning decisions.œ For each project, the CNDP sets up a Special Commission. Centred on a project file containing the objectives and characteristics of the project, the public debate may last no longer than four months. The Special Commission may also commission additional expert surveys.

Following the Aarhus Convention, public debates were reformed by the Law of 27 February 2002[30] on local democracy, based in particular on a study commissioned from the Council of State[31]. The declared objective of the law was to broaden and improve the scope of the procedure. A decree of the same year set out its provisions[32].

In accordance with the Aarhus Convention, that law also included a new chapter entitled 'Public participation in the formulation of planning or infrastructure projects having a major impact on the environment or local or regional planning', thereby reinforcing the role of the CNDP, besides making it into an independent administrative authority. In addition, while the 1995 law addressed the objectives and main characteristics of projects, with the 2002 reform their appropriateness is also taken into account.

This last point has attracted criticism, some considering it to be no more than a masquerade to lull the public. To these critics, the appropriateness of projects cannot really be challenged, and in no circumstances does the principle behind their execution depend on stakeholders expressing their opinion. But on the other hand, it might be argued that, by opening the possibility of such a debate on the appropriateness of projects, the legislator has given the public debate a new dimension, ensuring public participation throughout the project formulation stage, from the preliminary surveys to the completion of the public enquiry, so that it is no longer limited only to "options" concerning project execution.

By putting the CNDP in charge of organising the debates, the public is provided with valuable guarantees. The CNDP is the guarantor of their impartiality, transparency and sincerity. Moreover,

29. Order nº 2012-11 of 5 January 2012, which amends the procedures for formulation and revision of Territorial Cohesion Plans (SCoTs), Local Urban Development Plans (PLUs) and Municipal Maps (CCs). Article 6 concerns concertation.

30. Law nº 2002-276 of 27 February 2002.

31. Nicole Questiaux (Ed.), *L'utilité publique aujourd'hui*, Documentation Française, 1999.

32. Decree nº 2002-1275 of 22 October 2002, codified in Articles L.121-1 to L.121-15 and R.121-1 to R.121-16 of the Environment Code.

the desire to make them genuinely open debates has been shown both on paper and in practice. It is also the CNDP's responsibility to ensure that the public is properly informed "throughout the stage of execution of the projects referred to it, up until the receipt of the equipment and works", which should make it possible to monitor the fulfilment of the commitments undertaken by the contracting authority.

In the same spirit of openness, and in accordance with the Council of State's suggestions, the referral of projects to the CNDP was broadened in 2002[33]. Moreover, since the first debate held in 1997 on the planned expansion of the port of Le Havre, known as "Port 2000", the mechanism has seen a marked acceleration following the 2002 reform. Whereas six debates were held in five years prior to the reform, some thirty have taken place since, concerning both transport infrastructure (airports, roads and railways, high-voltage transmission lines, sea ports, *etc.*) and energy infrastructure (EPR nuclear reactor), or purely environmental considerations.

The scope of the public debate procedure has thus been markedly extended by the new provisions of Article L.121-8 of the Environment Code. Admittedly, the Commission deals with only large-scale projects, but they are nonetheless defined in a slightly different way[34].

The involvement of stakeholders and the public is indeed undeniable, and has also been relatively increased. Added to that is the fact that the CNDP can request further information from the contracting authority, with a view to satisfying as far as possible both its own and the public's demands for knowledge, which also enables the debate to remain objective, since the exhaustive nature of the information provided tends to offer proof of its sincerity.

Finally, the Law of 12 July 2010, Grenelle 2, sets out the post-debate monitoring procedures, opening the possibility of appointing a "guarantor" to ensure compliance with the public information and concertation procedures after the public debate.

One could say that sincerity and exhaustiveness are the keywords of the public debate. The CNDP retains complete freedom to ensure proper information provision and participation. The objectives of the debate procedure also include the transparency of the project files, equal access to information and equal treatment of participants.

The Aarhus Convention, meanwhile, provides that "the way in which public authorities make environmental information available to the public is transparent and that environmental information is effectively accessible"[35], and the CNDP adds, in contrast to the French Environmental Charter, that "the information must be comprehensive, clear and comprehensible to all"[36]. The only circumstances which may lead the CNDP to refuse to organizing a public debate have to do with confidentiality, in particular industrial confidentiality or national defense secrecy, and issues relating to the materiality thresholds of projects.

The public debate reforms have enabled stronger participation, which is a notable point enabling to make the distinction between the public debate and the other existing participation procedures, namely the public enquiry and the concertation provided for in the Urban Planning Code.

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33. The largest-scale projects must henceforth be referred to the CNDP by the contracting authorities (or the public corporation responsible for the project) or by the Environment Minister (in conjunction with the minister concerned), with a view to the organisation of a public debate on the overall environmental or planning options. Over the past two years, that possibility has been used in respect of the management of radioactive waste (debate of 12 September 2005 to 13 January 2006), the issue of transport in the Rhone Valley and the Languedoc Arc (debate of 27 March to 26 July 2006), and nanotechnologies (debate of 15 October 2009 to 24 February 2010).

34. They are henceforth "planning or infrastructure projects of national interest of the State, local or regional authorities, public establishments or private companies [...], if they are of major economic importance or have a significant impact on the environment or local or regional development".

35. Article 5(2) of the Aarhus Convention of 25 July 1998.

36. One might add to this certain provisions of the Environmental Concertation Charter (produced by the Ministry of Regional Planning and the Environment on 5 July 1996), which, although it has no legal force, is more precise in stating that "the information shall be comprehensive, accessible to non-specialists, permanent and balanced" (Article 4).

Conclusion

Community law has, under the leadership of international law, made unquestionable advances. In French law, when it is undeniable that no insignificant progresses have been made, they are nevertheless far from being perfect: undeniable progress in terms of informing the public, far less as regards participation and, above all, taking into account of the public's views. These developments in French law fall far short of the expectations of the civil society representatives' expectations and of citizens'.

Today the citizens' participation is nevertheless an element of democracy whose importance cannot be played down or ignored. The Barnier Law and the Environmental Charter confirmed that obligation[37], while some consider it as not being an obligation for the government, but a duty for stakeholders[38].

Thus, having acquired a new role, that of "guarantors of a higher collective value"[39], citizens should now enjoy, in the context of participation, a new political legitimacy. But here does the legislator intervenes with force, taking it upon himself to limit that right to participation, in a desire to strike a balance between the government and citizens.

As a result, that notion of the citizen has disappeared – if it ever became established – making way for a more practical, more malleable, more all-encompassing notion: "gouvernance à cinq", or "five-way governance". The Grenelle Environment Forum gave birth to this "new five-way governance for a democracy built on new foundations"[40], a notion encompassing a range of official actors, representatives of the State, members of parliament and local councillors, employee unions, companies and associations.

Some will say that this governance is nothing but "the emergence of a new bond between government and citizens [which] makes it possible to renew the traditional confrontation between the defence of the public interest [and] the supposed illegitimacy of private or sectoral interests brought by civil society"[41]. But so far, this notion of "five-way governance" has led only to the establishment of degrees of "representativity", in particular for associations, as shown by a decree of 12 July 2011 on "the reform of approval for associations and procedures for appointing approved associations, organisations and foundations recognised as being of public utility to certain consultative bodies whose purpose is to examine environmental and sustainable development policy"[42]. It sets out the conditions which must be fulfilled by associations in order to participate in the different environmental consultation processes. One of the key points of this initiative is mentioned in one of the implementing orders of that decree[43], which provides that an approved national-level association must show proof of having at least 2 000 members across six regions, while a foundation, in

37. In particular, by confirming the right of each individual to live in a healthy environment and the right of all to have access to information concerning the environment and to participate in public decision-making that has an impact on the environment.

38. See, to this effect, Pierre Ferrari, Les droits des citoyens dans leurs relations avec les administrations, *AJDA*, 2000, p. 471, and Les devoirs de l'homme dans la Charte constitutionnelle de l'environnement, *in Confluences. Mélanges en l'honneur de Jacqueline Morand-Deviller*, Montchrestien, 2007, p. 879.

39. Michel Prieur, 'Le droit à l'environnement et les citoyens: la participation', *Revue Juridique de l'Environnement*, 1988, p. 397.

40. "Une nouvelle gouvernance à cinq pour une démocratie refondée" was a term used by the Grenelle rapporteur-general, T. Tuot, in the general report of the Ministry of Sustainable Development, Planning and Ecology of October 2007, following the Grenelle Environment Forum.

41. *BDEI* 2006, p. 46, "Exigence d'information et de participation du public en matière d'environnement: perfectionnement des procédures de mise en œuvre", Catherine Ribot.

42. Decree n° 2011-832.

43. There are three in all: Order of 12 July 2011 on the composition of the application form for approval of environmental protection associations, the approval renewal form and the list of documents to be submitted annually; Order of 12 July 2011 laying down the procedures for application at national level of the condition set out in point 1 of Article R.141-21 of the Environment Code, concerning associations and foundations wishing to participate in the environmental debate on certain bodies; Order of 12 July 2011 laying down the composition of the application form for participation in the environmental debate on consultative bodies.

order to be recognised as being of public utility (*i.e.* gain charitable status), must provide proof of a membership of at least 5 000.

Some consider that such a reform could contribute to both increasing the importance of associations and refining the representative system, heading in the direction of five-way governance and confirming still further the notion of legitimate representatives of civil society. But, on the other hand, one might ask whether the government, in so doing, has not put a definitive check on the notion of "public participation", showing once again its fear of that participation, seeing it as a Pandora's box.

Some developments, however, allow us to envisage a slightly less bleak future. For example, most opportunely, the Council of State's latest annual report addresses participation[44], putting forward 18 measures aimed at strengthening the "principle of deliberative government", in particular concerning citizens' participation as early as possible in decision-making processes.

It recommends to improve in particular the impact and the taking into account of stakeholders' views, offering them an influence on the final decision akin to that of the members of five-way governance, which would be sure to establish for the future a direct, unquestionable bond between citizens and public decision-makers, so that their interests are genuinely and effectively taken into account.

The Council of State's report seems to show a desire to move towards greater cohesion in the mechanisms for participation, centred on citizens, since the channels currently available to stakeholders appear too limited.

Meanwhile,, the Conseil Constitutionnel (Constitutional Council), in October 2011[45], three years after confirming the constitutional value of Article 7 of the Environmental Charter[46], and hence the principle of participation, acknowledged that it could be relied upon in the context of a priority question of constitutionality concerning the lawfulness of regulatory provisions[47]. This decision is not insignificant, and perhaps signals a new chapter as regards the resonance of provisions concerning the participation and taking into account of citizens' views. In the broader context of environmental law, the decision likewise increases the importance of that law itself in a constitutional context[48].

44. See Conseil d'État, Rapport public 2011: *Consulter autrement, participer effectivement*.

45. Decision of the Constitutional Council nº 2011-183/184 QPC of 14 October 2011.

46. Decision of the Constitutional Council nº 2008-564 DC of19 June 2008.

47. See, to this effect, Bénédicte Delaunay, 'La pleine portée du principe de participation', *AJDA*, nº 5, 12 February 2012, p. 260.

48. See, to that effect, Chantal Cans, 'La charte constitutionnelle de l'environnement: évolution ou révolution du droit français de l'environnement', *Droit de l'Environnement*, nº 131, September 2005, pp. 194-203.

Public policy in environmental science and technology confronted with the challenge of sustainable development

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A scientific research policy is a complex subject to decrypt: understanding how it deals with the questions raised by sustainable development with greater or lesser effectiveness could be presented from a general political viewpoint or, as here, from a more personal perspective.

I would like to try to understand how a modern, ecological public science policy can be constructed. Far from mistrusting technological progress, this policy would examine its environmental consequences on an appropriate scale, free of negative or positive judgements about the very notion of progress itself.

Such a policy would aim primarily to understand the impact of human activity on how the biosphere functions on every level, and to highlight the conditions for resolving any negative consequences. It would necessarily incorporate ecological science, which is vital in untangling the fundamental functioning of the biosphere. However, it would not claim to seek the solutions that initially appear essential for avoiding the harmful effects of our activities and innovations. Not because this is not important, but because it could be considered in a liberal world that it is the responsibility of the economic actors themselves. The public sphere should stay above the debate and not propose solutions – or become entrenched in them – but should lead an ambitious regulatory policy that is technologically neutral and informed by knowledge. This would avoid any bias in its capacity to evaluate technological choices it has itself contributed to developing.

Let us begin with Jacques Ellul's book "The Technological Bluff"[1]. This book, the testament of a man who spent his whole life thinking about technology, was recommended to me by Michel Sébillotte[2] one day when, during a futurology exercise, our discussions drifted towards technology. In *Ultima verba*, the last chapter of his last major book, Jacques Ellul emphasises that "*Our knowledge is not on the same plane as our uncertainties, which are not of the same order or in the same sphere of comprehension as phenomena.*" This phrase reminds us that in our aspiration to progress we have an unfortunate tendency to adopt an unthinkingly optimistic attitude. We willingly minimise the environmental disasters that underlie our economic activities in favour of an illusory view of our knowledge and technological potential, which appear to us as sufficiently autonomous and well-developed to enable us to overcome them. And yet today we cannot subscribe to an extreme vision of technology that sees it as responsible for all the ills of the planet.

1. Jacques Ellul, *The Technological Bluff*, Hachette, Paris, 1988
2. Michel Sebillotte (1934 – 2010) was a French agronomist. As well as a number of contributions to agronomy, he led several forecasting projects.

Let us be clear: technological research should not be excluded from public research policy. But technology should remain what it is, and not be confused with or replace environmental research in the collective interest. This possible confusion quickly arises: from a perspective where solutions to damage are necessarily entrusted to technological progress, the clear risk is that environmental research be confused with this pursuit of public technological research.

My hypothesis is that the economic and technological world adapts most effectively when stimulated by a strong desire to protect the environment, or at least more effectively than in the current situation, where the public sphere adopts weak compromises while guiding the technological options.

To illustrate this hypothesis, I shall analyse situations that are familiar to me, and in particular that of French environmental research subsequent to the Grenelle Environment Round Table; I believe this analysis can probably be generalised to other countries. I will remain within my own personal perspective: I will explain why and how my responsibilities have gradually brought me to a position of mixed feelings about how the reflex development of research policy ultimately leads to a failure to address the major environmental issues of sustainable development.

The opportunities of my professional life and, I hope, some ability, have enabled me to exercise a role as a senior French civil servant in (among others) both the ministries with responsibility for these questions: the research ministry and the environment ministry[3]. I moved from a post in which my job was to develop the research fabric and technology transfer to business in a large French region to a post where I had to contribute a scientific, future-oriented perspective to public policy on ecology and sustainable development. It was here that I became aware of a fierce antagonism between the culture and approaches of the two ministries. This has nothing to do with competition and the conflict created by individual ambition[4]. It is rather a question of cultural differences that are ultimately fairly intractable. This antagonism seemed to me to culminate in the Environment Round Table, a point when these differences crystallised against a background of shared ecological ambitions.

Applied knowledge for some, uncertainties for others

This opposition arises from the different priorities placed by the two ministries on two areas of investigation, that of knowledge and that of uncertainty, which ultimately place them in two distinct and almost entirely independent camps. The world of science and technology is primarily concerned with discovery, with the development of human genius that will raise mankind up thanks to the benefits of technical progress. Confidence for the future is located in the development of knowledge from a Promethean perspective. In the area of ecology, scientific knowledge obviously exists that allows us to pursue the understanding of life, its evolution and the functioning of its various assemblies. But the main problem is the scale of the uncertainty, the extent of what statisticians call chance – *i.e.* what we do not know. The defenders of nature are convinced that this chance is where the problems lie that we need to face in building sustainable development and on which the missions of their ministry are founded. Confidence for the future is thus located in humanity's ability to understand better the context of its actions. Engineers account for this chance, this unknown element, as a simple parameter of the confidence interval of their project, a parameter that enables them to judge the probability that its developments will be operational with a confidence of, for example, 19/20, where what they want to exploit is located. For researchers in the environmental sciences, this chance, controlled rather than truly understood, is a locus for phenomena which, if we are not careful, can cause global disasters. Knowing them better allows us to conceive of development that is "sustainable by design".

3. It is a strength of inter-ministerial civil servants that they can move between administrative structures.

4. It is exceptional in today's world, but in fact the main thing the staff of these two ministries have in common is that they are in no way comparable in terms of career progression with the heights of social promotion in the civil service. The many friends I made in these two posts were all much more motivated by their work than by their careers.

The role of the precautionary principle

This dichotomy partly explains the polemics about the precautionary principle. For some, the eventuality of environmental or health risks is part of the background noise, a kind of price that must be paid for progress. They implicitly subscribe to the idea that the benefits of bringing products or services born of scientific progress to the market easily outweigh these uncertain risks, risks which in any case will be remedied easily as their first occurrences are observed. Others focus their concerns on the risks. They cite the many cases of unanticipated damage to the environment to justify a prudent attitude and the need to evaluate progress in detail before generalising any innovations.

The idea of political control over innovation is anathema to those who denounce the precautionary principle. Despite jurisprudence showing that very few innovations have truly been constrained by the application of this principle, they see a serious risk that progress will stagnate, accumulating examples of supposed delays in the areas of health, agriculture and industrial innovation. They are similarly reluctant in biomedical ethics but seem more timid about this, as morality is more deeply rooted in medicine and human research than in the field of the environment. Moreover, it would seem that the application of these ethical measures produces greater quality in the research itself.

At the same time, many Court cases and public decisions have used the precautionary principle wrongly, associating its application with criteria that have little basis in rationality. One example is the now famous judgement by the Versailles Court of Appeal which refused permission for a mobile telephone mast solely on the basis of fears among the local population that its presence could affect their health.

How can we envisage a science policy that balances the importance that scientific discoveries can bring to everybody's well-being, to humanity and even to the environment with research into environmental risks? The issue is how to get away from this ambiguity about the goals of knowledge and of research policy. Resolving this is essential in order to leave sterile polemics and irrational anxieties behind: without a serious increase in scientific knowledge to explain nature and the level of risk, everyone will respond on the basis of faith and destructive Manichaeism. Faith may enable the individual to live with his own anxieties, but ultimately it contributes relatively little to the progress of humanity in the area of science!

The example of the Environment Round Table

Many participants in the Environment Round Table contacted during the consultation phase observed that research in the field of health and environmental risks was inadequate. They called on the government to react. The horizon seemed to be clearing: the political will finally seemed to be present and resources available.

The second phase of the Round Table was conceived as the State's operational appropriation of the results of the initial debate between the stakeholders. Operational committees (COMOP) were set up following difficult inter-ministerial discussions, their compositions carefully weighed and balanced. Research was entrusted to a "Research Comop". Its composition is public, and anyone can consult it: real environmental specialists alongside specialists in technological research whose awareness of ecological issues was either personal or recent, but certainly not a scientific specialism. The words of Pierre Bourdieu[5] on committees composed of "*particular agents sponsoring particular interests with wholly unequal degrees of universalisation*" inevitably come to mind.

The text of the committee's report explains several arguments in favour of environmental technologies. For example, the justification for research into carbon gas storage contains the sentence: "*Applications in France are limited by the size of our economy, but there is a potential export market where French companies will have a non-negligible role to play.*" Does industrial policy appear more justifiable than the goal of protecting the environment? The ambition, laudable in itself, to

5. Pierre Bourdieu: *Sur l'Etat* (course at the Collège de France 1989-1992), published by Editions du Seuil, 2012.

develop more ecological aircraft also has to make do with a formulation that is clumsy to say the least: "*The juxtaposition of existing programmes with this one must allow for a family of aircraft to enter service by 2017 with the benefit of technological breakthroughs that make the successors of the A320 family competitive with the future B737*." Here the Round Table comes to the rescue of industrial policy while potentially adding fuel to the international legal case on public support for the aerospace industry and its mutual hypocrisies in the rivalry between the US and Europe! Some might see this as conscious collaboration between the economic and ecological pillars of sustainable development, but this view will not stand up to serious analysis for long.

It is not the importance of technological research in promoting green growth that poses a problem, but its role in the efforts of the State. It is the new constraint of the environment rather than the operation of an autonomous, independent market that seems to justify an increased public effort on green solutions for the world of technology. I imagine, with some confidence in their economic lucidity, that few public or private laboratories currently spend their research resources on developing processes or products that cause pollution and consume high levels of energy[6]! As a correlation, there is no evidence that such research is more onerous than traditional technology research.

The (in)constancy of French research policy

Budget data[7] shows that our country has a chronically low level of private research (see figure 1). Great efforts have been made to make our companies innovative, at considerable cost to the public finances. It is legitimate to wonder whether this spoon-feeding may be having a perverse effect on our industry's appetite for innovation. Is it effective to continue this support for environmental

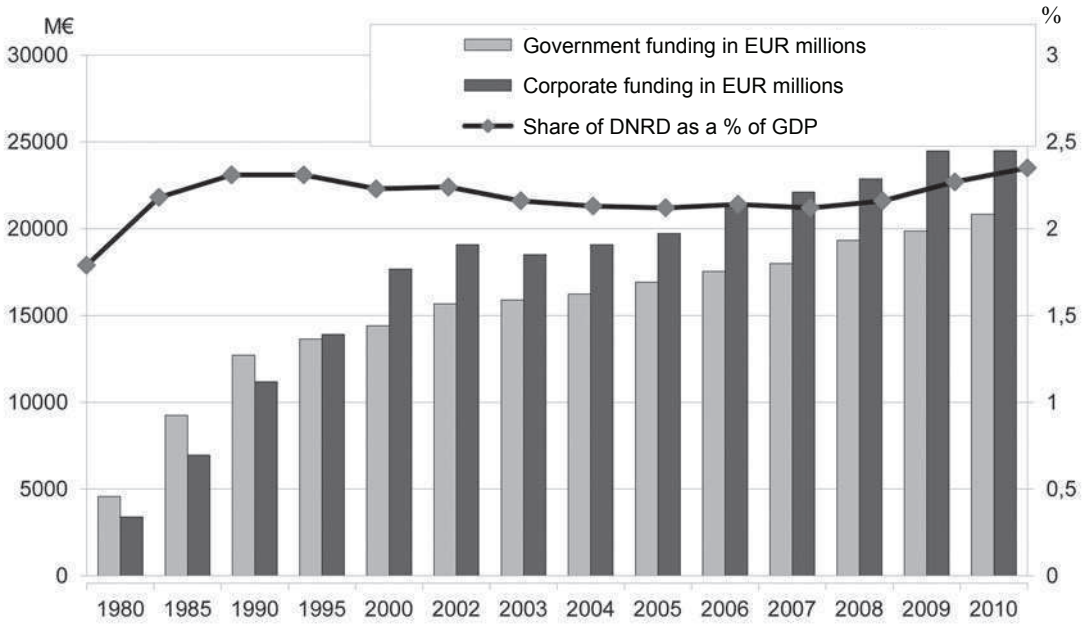

Figure 1. Evolution of funding for French national research by the public sector (government) and the private sector. *Source:* Jaune Recherche 2012.

6. I hope the reader will see more optimism than naivety in this sentence!

7. The reference document is the appendix to the draft finance act entitled "Report on research and higher education policy", known as the "Jaune Recherche", *http://www.performance-publique.budget.gouv.fr/farandole/2012/pap/pdf/Jaune2012_recherche_formations_sup.pdf*

reasons, contributing yet more State resources to research that is financed by industry in competitor countries, with much less public help? Does the environmental question not deserve better than to be a new alibi for grants to the detriment of vital research into what is happening? Is generic support through the research tax credit and the many mechanisms for bringing public research and business together not enough to bring out the industrial competitiveness that is not currently able to overcome the constraint of the environment?

Analysing, understanding, acting, adapting…

Public research should also seek to understand the mechanisms of the market and develop instruments to promote behavioural change in consumers and citizens, without which all innovations, however virtuous, will remain fruitless. The Round Table's Research committee seemed to ignore these elements, even though they were present in the initial debate.

Instruments to regulate the environment do exist, whether they be standards, emissions trading schemes, compensation or environmental taxes. We need serious knowledge of the environment and humanity's impact on it to construct instruments that are fair and effective. Figure 2 shows that France is behind other countries in northern Europe in the development of environmental taxes. A targeted effort to develop these regulatory instruments therefore seems possible, deliberately penalising the most polluting technologies in favour of those that innovate in terms of their environmental impact. An essential condition for establishing these tools wisely (including environmental taxes) is to escape the influence of pressure groups on one hand and the dominance of the technological culture on the other.

Despite its faults, the Round Table did succeed in raising awareness of the issues. The operational committee entitled its chapters "Analysing and understanding, acting, adapting". The text reflects a desire for global knowledge about the environment and the position that action, while important, will not be enough without some adaptation by humanity to these new constraints. "Observation, analysis and forecasting are essential steps. However, they cannot be dissociated from the organisation of research," states the committee's report. This sentence clearly expresses a call for a research

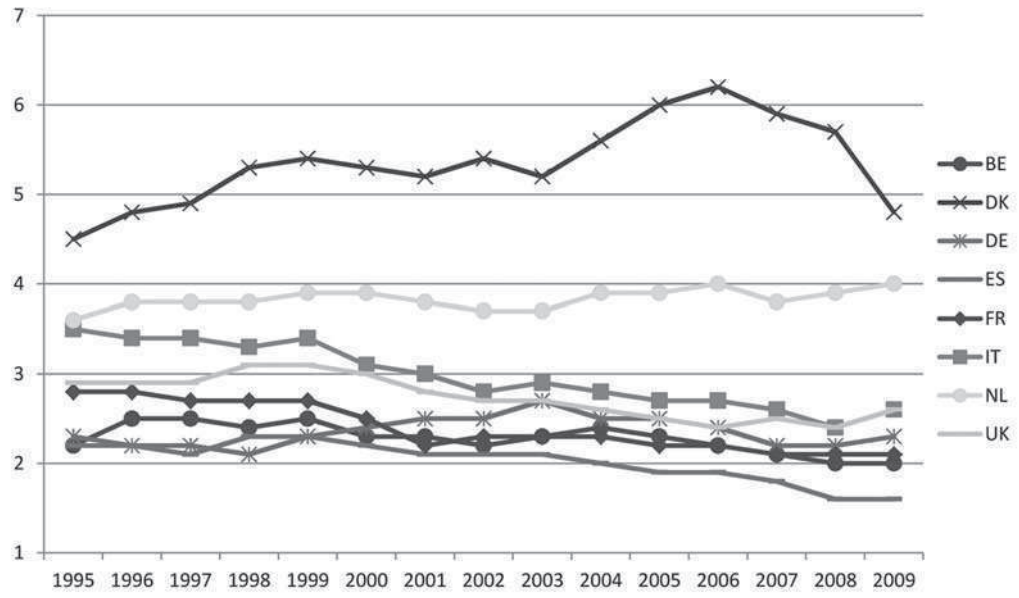

Figure 2. Evolution of environmental taxes in different countries in Europe over time.
Source: **Eurostat 2011, Taxation trends in the European Union.**

orientation that will benefit understanding of environmental phenomena, and not just support for technological innovations, however "green" they may be.

In particular, the Research committee recommended further efforts from the National Research Agency (ANR) in terms of scheduling environmental research. €200 million were proposed for the priorities of Health-Environment, Agriculture-Biodiversity-Habitats and Cross-Disciplinary Actions. I will spare the reader a precise breakdown of the budget figures, but they are unambiguous (see table 1). The credits allocated to these priorities, and thus to the relevant departments at the ANR, have fallen considerably after a brief increase in 2008 and 2009. If we compare the four years' credits for these departments with the average funding in the years 2005 to 2007 reconstituted over four years, the total cut is €-74.5 million, compared with the committee's recommendation of €+200 million over the same period.

In this overall reduction in the credits allocated to themed programmes in favour of the non-themed programme, the ANR has only been able to save the so-called "competitiveness" credits to help businesses develop new technologies. The ANR would certainly emphasise that credits for the "programme blanc"[8] are also allocated to environmental subjects according to demand. In fact, analysing the results of these programmes shows that the resources are very limited: €23 million in 2010[9] for the related subjects of Biodiversity, Evolution, Ecology and Agronomy and Earth System, Environment, Risks, and probably does not make up for the drop in funding for themed programmes. In addition, the "programme blanc" finances research that is mostly fundamental in nature: it may be thought that its aim is very remote from the precise objectives set for research by the Round Table.

In small steps, the positive intentions of the Round Table in terms of environmental research[10] have ultimately been reflected in few significant changes. However slight they may be, they essentially involve voluntary action by research organisations, which have redeployed their credits without seeing their efforts truly rewarded in terms of budgets or active programming by the ANR. Time will tell whether the new organisation of national research establishments into alliances[11] and the role of the alliances responsible for the environment and energy within the national research and innovation framework will enable the lines to be moved further.

The new awareness at State level is also making progress within the ministerial department in charge of industry. In 2006, the industry minister François Loos wrote in the preface to the work "Key Technologies for 2010[12]": "Our fellow citizens expect technology to hold the key to sustainable development." The creed of technology held full sway! The five-year review "Key Technologies for 2015" admits to several errors in the past: although it remains focused on technological investment, the report gives furtive voice to the idea that it is also important to act in the market: "France has successfully acquired a leading position in the nuclear field. Significant budgets have also been devoted to other sectors, and particularly the area of renewable energy: geothermal, solar *etc*. However, these were cut sharply between 1986 and 2000, a period of low fuel prices following an initial collapse; in addition, the purchase prices for the electricity produced from these emerging energy sources provided very little incentive. One consequence was that the corresponding industrial sectors remained embryonic, with just a single manufacturer of photovoltaic cells, for example. From this point of view, countries such as Denmark, Germany and Japan have been able to develop a significant industrial fabric." The rest is history!

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8. The "programmes blancs" or white programmes are calls for proposals that do not specify final goals. The selection criterion is the scientific excellence of the proposal.

9. Report on ANR activity in 2010. *http://www.agence-nationale-recherche.fr/magazine/documents/detail/rapport-d-activite-2010-annual-report/*

10. The environmental emergency aspect of the national research and innovation strategy later confirmed that this was a national priority.

11. The creation of research alliances breaks down barriers in the relationships between actors with shared legitimacy in a particular field and develops coordination and partnership initiatives (from the gouvernement.fr site).

12. Les Éditions de l'Industrie, Paris, 2006.

Table 1. Evolution of the ANR budget by research area. The first two lines correspond to the programmes concerned with the Environment Round Table.

ANR budget (in EUR millions)	2005	2006		2007		2008		2009		2010		2011
	Executed	Executed		Executed		Executed		Executed*		Executed*		Budget**
	Grant	Grant	Ress. Conv.	Grant	Ress. Conv.	Grant	Ress. Conv.	Grant	Ress. Conv.	Grant	Ress. Conv.	after DM1
Sustainable energy and environment	97.3	111.7		86.7	1.5	102.6	1.5	84.9	1.5	75.1	1.5	73.6
Ecosystems and sustainable development	47.3	50.5		44.5		60.1		55.7		29.2		27.8
Science and information and communication technology	130.5	146.6		126.9		128	0.6	122.5	3	91.9	1.7	79
Biology and health	102.6	124.1	0.5	131.1	3.3	120.4	2.3	110	4.8	65.8	3.4	65.7
Humanities and social sciences		13.2		18		16.6		7.6		9.7		8.4
Engineering, processes and safety				39.6	3.4	44.7	3	39.9	4.5	30.2	4.2	26.6
Non-thematic and cross-disciplinary	161.5	172	2	152.4		164.8		215.8		303.6		272.5
Total for programmes	**539.2**	**618.1**	**2.5**	**599.2**	**8.2**	**637.2**	**7.4**	**636.4**	**13.8**	**605.6**	**10.7**	**553.6**
Partnerships and competi-tiveness	129.7	158.4	0.1	185.1		138		109.4		122.4		119
Praecipium				22.4		50.6		54.2		56.3		56.2
Management expenditure	19.9	19.9	0.1	17.8	0.4	13.7	0.3	16.4	0.5	11.9		3
Grand total	**688.8**	**796.4**	**2.7**	**824.5**	**8.6**	**839.5**	**7.7**	**816.4**	**14.3**	**796.2**	**10.7**	
		799.1		**833.1**		**847.2**		**830.7**		**806.9**		**731.8**

*Excluding recovery plan; **Excluding forward-looking investments.
Source: ANR (French National Research Agency) "Jaune Recherche 2012", already cited.

While a budgetary analysis is useful to support an argument with precise figures, it is unfortunately only possible at the required level of detail on the scale of each individual country. However, the French situation as described in the first part of this text is unfortunately likely not to be an exception among the member states of the European Union. But the budgetary analysis would have to be conducted for each country.

And now?

The European Union itself, which plays a major structural role in terms of public policy on environmental protection, does not seem to place a high priority on environmental research. The 2010 data for the seventh framework programme for research and technological development[13], an extract from which is shown in table 2, illustrates this with the amounts allocated to research on energy and the environment of 7 % and 4.5 % of the budget respectively, including Euratom[14] in the energy figure.

Thus the political entity that is probably the most advanced in terms of political will and concrete measures for environmental protection does not place a very high importance on research to support this policy. The budget lines relating to information and communication technologies, health and nanotechnology represent much higher sums than the environmental lines. The Europe of the seventh FPRTD remains firmly in a technological dynamic where technical solutions to environmental problems and the correction of health problems with more and more powerful medical treatment win out over the development of preventive policies informed by research.

The document "Horizons 2020"[15], currently in the consultation phase among member states, is a scientific strategy document for Europe which it is interesting to analyse in the light of our problem. The strategy aims to develop "research and innovation […] at the heart of the Europe 2020 strategy to promote smart, sustainable and inclusive growth." Research is described as a way to "maintain high standards of living while dealing with pressing societal challenges such as climate change", but apparently not the erosion of biodiversity. It helps to "deliver jobs, prosperity, quality of life and global public goods." The characteristics of the programme include "a strong focus on creating business opportunities out of our response to the major concerns common to people in Europe and beyond, *i.e.* 'societal challenges'." The European strategy has three aspects: scientific excellence, industrial primacy and social challenges. We might therefore expect this third aspect to include elements such as knowledge of the planet, the operation of ecosystems, determinants of environmental health or the impact of pollutants *etc.* In fact, "This will cover activities from research to market with a new focus on innovation-related activities, such as piloting, demonstration, test-beds, and support for public procurement and market uptake." We are thus clearly in a traditional mode of research funding that targets solutions rather than knowledge of the issues. We can take the fact that "at least 60 % of the total Horizon 2020 budget will be related to sustainable development", rather than all of it, as a naive lucidity on the part of the authors about these oppositions between technological solutions and the need for knowledge.

The European text does present a few expressions that show an interesting evolution in mentalities, however. For example, although (in a somewhat strange phrase) "Stronger support will be given to the market take-up of innovation, including by the public sector," we note that "New approaches such as inducement prizes, that reward the achievement of specific goals, will encourage the involvement of a wider range of innovators. The European Innovation Partnerships will be tasked with tackling technical, legal and operational barriers to innovation in Europe, hereby establishing solid links between supply and demand side measures." We have to look closely, but

13. 2011 report on the VIIth FPRTD, *http://ec.europa.eu/research/reports/2011/pdf/fp7_annual_report_statistical_annex.pdf#view=fit&pagemode=none*

14. Euratom (or EAEC, European Atomic Energy Community) is a European public body responsible for coordinating research programmes into nuclear energy.

15. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Horizon 2020 – The Framework Programme for Research and Innovation. COM 2011, 808 final.

Table 2. Breakdown of credits in the VIIth Framework Programme for Research by priority area in 2010. Extract from the 2011 annual report of the VIIth FPRTD.

Table 3c: FP7 Grant holders by the country of origin in 2010		Member States			Candidate Countries			Associated Countries			Third Countries		
Priority Area		No. Grant Agreements	Partici-pations	Participant EC Contribution (€)	No. Grant Agreements	Partici-pations	Participant EC Contribution (€)	No. Grant Agreements	Partici-pations	Participant EC Contribution (€)	No. Grant Agreements	Partici-pations	Participant EC Contribution (€)
IDEAS	European Research Council	494	538	792 910 575	0	0	0	87	89	154 532 828	3	3	332 578
PEOPLE	Marie-Curie Actions	1 427	2 407	518 138 987	79	86	9 423 173	223	261	62 451 212	33	34	1 890 366
EURATOM	Nuclear Fission and Radiation Protection	44	519	97 174 473	0	0	0	17	23	3 759 061	11	17	2 570 162
CAPACITIES	Research Infrastructures	66	652	203 117 358	10	19	2 948 284	33	74	24 548 193	17	68	2 244 078
	Research for the benefit of SMEs	164	1 350	192 132 117	30	42	5 500 866	42	79	13 102 542	5	5	257 500
	Regions of Knowledge	8	112	16 746 211	1	10	338 511	3	10	860 746	0	0	0
	Research Potential	19	27	37 048 640	3	3	4 286 339	3	3	3 712 327	3	6	1 341 062
	Science in Society	26	236	40 499 842	3	4	378 661	13	20	2 757 328	9	17	1 218 840
	Support for the coherent development of research policies	3	3	1 400 000	0	0	0	0	0	0	0	0	0
	Activities of International Cooperation	22	80	9 179 776	4	4	446 584	4	5	480 563	21	66	6 384 918
COOPERATION	Health	157	1 595	757 065 208	12	17	3 469 441	78	127	53 533 731	71	190	52 667 903
	Food, Agriculture and Fisheries, and Biotechnology	65	662	177 067 439	10	12	1 417 542	31	54	13 054 587	30	94	9 544 757
	Information and Communication Technologies	352	2 898	1 097 135 062	11	12	1 969 526	158	239	98 287 841	45	94	7 404 363
	Nanosciences, Nanotechnologies, Materials and new Production Technologies -	95	1 045	343 906 357	6	6	1 282 021	40	80	32 297 669	11	21	2 709 537
	Energy	48	495	205 591 233	2	3	452 097	27	53	19 738 744	12	21	1 528 615
	Environment (including Climate Change)	90	1 007	224 507 392	16	28	2 595 118	50	83	18 510 833	35	165	18 814 534
	Transport (including Aeronautics)	75	919	235 235 470	5	5	527 540	20	29	7 387 585	19	40	3 095 557
	Socio-economic sciences and Humanities	32	298	64 659 829	5	6	774 279	15	18	4 851 313	9	35	4 529 188
	Space	59	422	95 741 678	2	2	172 567	16	22	7 837 974	25	59	4 871 778
	Security	37	411	157 521 292	3	4	463 788	20	31	13 328 686	2	3	395 354
	General Activities	3	4	641 179	0	0	0	0	0	0	0	0	0
	Total	3 286	15 680	5 267 420 117	202	263	36 446 336	880	1 300	535 033 763	361	938	121 801 089

http://ec.europa.eu/research/reports/2011/pdf/fp7_annual_report_statistical_annex.pdf#view=fit&pagemode=none

we might see here a few weak signs of openness towards research into how economic policies incorporate environmental concerns not only as constraints, requiring the development of appropriate technologies, but as opportunities. Such changes would involve taking account of the global nature of these problems. However, this promising paragraph is immediately followed by a development of the priority to be given to key technologies – as a solution – putting our optimism into context!

Economic forces ahead of governments?

At international level, everyone knows the importance of the Intergovernmental Panel on Climate Change (IPCC) and its key role in achieving a global consensus on the impact of greenhouse gases on the climate. Apart from a kernel of resistance consisting essentially of American Republicans, the world now knows that human activity is causing a warming of the climate whose consequences vary according to region and sector but are often very serious.

It is interesting for our purposes to read the appeal issued before the Copenhagen summit by 500 European companies of all sizes coming together as the Prince of Wales Corporate Leaders' Group on Climate Change, a group led via a sustainable development programme at Cambridge University. They observed that the G20 countries were able to propose a joint response to the 2008 banking crisis very quickly, and that at Copenhagen they would have to reach a similarly decisive agreement on climate change. “Economic development will not be sustained in the longer term unless the climate is stabilised,” they stated. They called for “a sufficiently ambitious, effective and globally equitable deal [to] deliver the economic signals that companies need if they are to invest billions of dollars in low carbon products, services, technologies and infrastructure.” Just before Copenhagen, therefore, the business world was already leaving behind the logic of resistance, in which it wanted to retain the advantages it had gained and hold out its hand for subsidies, moving towards a logic of economic actors conscious of their responsibilities in terms of investment in research and development. They saw that the necessary changes were only possible with governance that would take global environmental issues into account.

The failure of Copenhagen was thus a failure of governments, unable to take collective responsibility even when economic forces and public opinion demanded it. The small hope of Durban and its rescue of the Kyoto protocol is unfortunately not enough to change this diagnosis.

The environment as a strength rather than a weakness: the first bricks of a green economy

Europe is providing a real-time test of the benefits of a demanding industrial innovation policy with the 2006 adoption by the European Parliament of the Reach regulations[16]. During negotiations following the publication in 2001 of a white paper entitled “Strategy for a future Chemicals Policy”[17], chemical manufacturers launched a barrage of extremely alarmist statements. Their economic studies “proved” that the cost/benefit analysis of the measures would be negative, and that the application of such regulations, more restrictive than in the past, would have a harmful impact on employment in Europe. The USA supported these positions, as the regulations were also likely to apply in their territory. The white paper planned to publish risk data as soon as it became impossible to deny the risks, opening the way to class actions and closing the European market to hazardous chemicals[18]. Of course these studies did not take the social cost of diseases associated with chemical pollution into account in their global assessment and, even more to the point, included no analysis

16. EC 2006. Regulation (EC) nº 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH).

17. EC 2001. Commission Communication, COM (2001) 88 final. White Paper on the Strategy for a Future Chemicals Policy. 27/02/2001, Brussels, Belgium.

18. This is a lawsuit brought by a large number of people who have all suffered the same harm.

Drawing by Robert Rousso *in le Courrier de l'environnement de l'INRA* nº 7.

of the effect of environmental constraints on innovation. It could however be supposed that stimulating the production of environmentally friendly chemicals while banning dangerous alternatives would give an economic advantage to European industry.

This competition based on environmental quality is now more important for the development of qualified jobs than competition based on production costs. The European chemical industry has now launched major research and development programmes and based its competitive strategy on the notion of green chemistry, a chemistry that not only avoids generating environmentally harmful waste but consumes energy economically and uses renewable raw materials. We have moved from a promised economic catastrophe at the time of the white paper to a virtuous circle of industrial innovation under environmental constraints after the REACH regulations were ultimately adopted.

The recent topicality of biodiversity

The most recent advance at global level is the creation of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). This panel of experts aims to inform

the world's policy-makers about the reality of our knowledge on the decline of biodiversity and its consequences for the ecosystem services from which humanity benefits. It originated with a French proposal formulated in 2005 which resulted in an initial mechanism, IMoSEB[19], and which has now finally taken concrete form. The evidence suggests that the existence of this kind of group of scientists will play a favourable role in developing biodiversity research and knowledge about ecosystems and their importance for humanity. IPBES is independent from the Convention on Biological Diversity but supports it in scientific terms. There will be struggles ahead to ensure that politicians take future IPBES recommendations into account and that real measures to protect biodiversity are put in place in all countries.

The fact remains that this advance shows a new global awareness of the need to understand how our planet functions, and not just in terms of the conditions for economic growth. It is the kind of good news that is enjoyed all too rarely. One of the most likely results will no doubt come in the agricultural world. The transition to ecologically intensive agriculture, *i.e.* agriculture that uses knowledge of how ecosystems function to feed the world's population sustainably, depends greatly on the science that IPBES will provide to the populations concerned.

Scientific research: rebalancing the scales

This strong focus of world expertise on climate change in a technological world leads to the paradox that the global need to mitigate and adapt to climate change is becoming more important for local politicians than the problems affecting their own territories. The air quality issue is an example of this. One of the most recent WHO studies[20] estimates the number of premature deaths linked to poor air quality in Europe's towns at 250,000. Particulate emissions from vehicle traffic are responsible for a large proportion of these deaths, and we may well wonder whether the enthusiasm for diesel vehicles due to their slightly lower CO_2 emissions than petrol engines is reasonable when it is such an obstacle in terms of health risks.

A balance is required between scientific support for public policy at global level and a level of enlightenment at least equivalent in local policy. Biodiversity management is especially symbolic of this requirement for interlocking levels of action.

Here the goal is not to preserve global functioning by controlling a small number of global anthropic contributing factors – such as CO_2 emissions – but to preserve extremely varied biological resources that are closely linked to their habitats and territories. This territorial link demonstrates the need for close collaboration between global governance and local policy and places constraints on how it should be organised: it could help highlight the importance of allowing actors to find their own solutions in a context where the diagnostic comes from outside. This is the mode of operation on which I am pinning my hopes, a mode in which environmental protection, informed by science, stimulates the creativity of all economic and social actors. A world in which the political and economic compromise between science, public research and technological competition, which promotes every possible conservatism, is replaced by ecological ambition, a source of creation which redefines everyone's role.

Conclusion

Awareness of the environmental emergency is now universal. All scientists concerned about the prospect of climate change or a collapse in biodiversity can bear witness that contemptuous remarks about "militant researchers", "ageing hippies", "utopians" or "bearded eco-warriors" are now only

19. International Mechanism of Scientific Expertise on Biodiversity.

20. *http://www.euro.who.int/fr/what-we-do/health-topics/environment-and-health/sections/news/2011/09/new-who-database-shows-poor-air-quality-in-cities*

found in the most reactionary of statements[21]. The study of climate change, the effects of pollution and biodiversity, while not yet real priorities that can be measured in budgetary terms, are no longer considered as minor sciences. However, there remains a very strong culture of technology as the universal solution to all our ills. This culture is understandable, and we cannot leave behind several centuries of economic development based on meteoric technological progress and cheap energy without a certain nostalgia. The mechanism is not unlike religious faith: it would be so wonderful if paradise existed, if all the problems we face could be solved solely by the law of constant technological progress. And yet our reflexes remain, muddying the waters between support for science and the potential of technology, especially when it comes to defining research policy. Today the world seems on the brink of a precipice, and international groups of experts are leading the way. Their prophecies are not optimistic. The credit crisis has also revealed the strength of ideologies based on promises and the blindness of politicians. Most policy-makers are still operating in the mode of the past. Let us formulate the wish that the researchers in Rio will understand that tomorrow's innovation is not an extension of yesterday's, and that there is an urgent need to better understand how our planet works at all territorial levels, to develop demanding public policy and ultimately to trust innovators and businesses to find ways of pursuing economic development in new forms. These few proposals could constitute the basis for a roadmap for a future UN environmental organisation, which, to my mind, must be equipped with a strong research policy.

21. They have not disappeared, though, if one opens one's eyes and ears!

II. Harsh reality

Climate change and food security. A crucial test for humanity?[1]

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"The best way to forecast the future is to invent it"
Steve Jobs

"Earth provides enough to satisfy every man's need, but not every man's greed"
Mahatma Gandhi

Today's agriculture is at a crossroads. Climate change is already impacting negatively food production while there are expectations for the sector to meet a rise in demand by 70 to 100 % within only 40 years. Failure to reach this target would further reduce food security, while success may commit the world to further warming by accelerating greenhouse gas emissions. Can we avoid a spiral of poverty, hunger, environmental degradation and conflicts by developing climate smart agriculture?

Nothing is more important to humanity and the stability of societies than a reliable and affordable supply of food. One of the great challenges of the XXIst century will be to increase the global food supply to accommodate a world growing to 10 billion or more people while preserving a safe operating space for humanity by avoiding dangerous environmental change (Rockström *et al*., 2009).

Of the 14 billion hectares of ice-free land on Earth, 10 % are used for crop cultivation, while an additional 25 % of land is used for pasture. Over 2 billion tons of grains are produced yearly for food and feed, providing roughly two-thirds of total direct and indirect protein intake; a mere 10 % of this total, or 200 million tons, is traded internationally. Resource management is key to achieve current production levels; for instance, although irrigated land occupies only 17 % of total arable land, irrigated crops supply a much higher portion of total production (ca. 40 % in the case of cereals) and consume 2,500 billion m^3 water, or 75 % of the total fresh water resources consumed annually. Finally, agriculture is a significant contributor to land degradation and anthropogenic global greenhouse gas emissions, being responsible for 25 % of carbon (largely from deforestation), 50 % of methane, and more than 75 % of N_{20} emitted annually by human activities (Tubiello *et al*., 2007).

Increasing demands for land are increasing pressures on biodiversity and natural resources. Agricultural expansion in the tropics is mainly based on deforestation, since 80 % of new tropical croplands are replacing forests (Foley *et al*., 2007), which affects biodiversity and key ecosystem services. Species-rich regions of the world are under pressure from agriculture conversion, putting at risk animal and plant species, including hundreds of medicinal plants that are the basis for global health care (TEEB, 2010). An estimated one third of the world's cropland is losing topsoil faster than new soil is forming. For example, analysts suggested that Africa has been losing 1 % of soil organic matter every year since the 1960s (Clay, 2011), resulting in inefficient use of inputs such

1. This text was first published as a chapter in the book *A Planet For Life* [Gravey V. *et al*. (Coords.), 2012. *Regards sur la Terre 2012. Développement, alimentation, environnement: changer l'agriculture?*] Armand Colin-IDDRI, Paris, 360 p.

as fertilizer and water and reduced grain harvests. These processes result in hunger spread and an increased dependence on food imports. Unprecedented water shortages are also increasingly apparent in many parts of the world. Over-extraction of ground water is shrinking the irrigated area, depleting aquifers and degrading soils through salinization.

Future population and economic growth will require a doubling of current food production, including an increase from 2 billion to above 4 billion tons of grains annually. Associated to continued dietary shifts from crop-based to livestock-based diets, such trends would require a large agricultural land expansion especially in sub-Saharan Africa and Latin America (Schmidhuber and Tubiello, 2007; AgriMonde, 2010).

The XXIst century global food crisis

Until recently, it was expected that despite climate change and increasing world population, there would be several decades with food surplus – and low prices – ahead (Easterling *et al*., 2007). Contradictory to this expectation, the volatility of world food prices has increased and two out of the last three years have been characterized by large spikes in international grain prices with some grains more than doubling in cost. This unforeseen onset of a global food crisis underlines our poor understanding of the complex interactions between food systems, world markets and climate.

In 2005-2006, a production shortfall, amplified by export restrictions in major countries like India and Argentina, led to a dramatic increase in food prices from 2007 to 2008 adding 40 million people to the chronically hungry category (FAO, 2008). Food riots broke out in 48 countries sometimes leading to high political instability (Brinkman and Hendrix, 2010). Subsequently, the summer of 2010 was exceptionally warm in Eastern Europe and large parts of Russia, breaking a 500-year-long seasonal temperature records over approximately 50 % of the European continent (Barriopedro *et al*., 2011). Associated dry conditions led to the loss of 1 million hectares from wildfires and crop failures of around 25 % for a total damage of about USD 15 billion. This heat wave prompted Russia to suspend exports, pushing grain prices towards an all time high in February 2011 and contributing to riots and changes of political regimes in the Middle East. In a tight world market, such events and similar ones are increasing food prices and pushing millions more people into poverty and hunger, thereby contributing to political instability and civil unrest.

Yet, the Earth still provides enough to satisfy every man's need. While a billion people go hungry, half a billion are obese. The global calories deficit reaches only 3 % of global supply by agriculture and could be compensated by reducing food over-consumption. Moreover, 40 % of the grains is used to feed livestock and an additional 6.5 % for biofuels. Furthermore, 40 % of the totality of global food products is either lost after harvest or wasted (FAO, 2011).

Climate change exposure of agriculture

Agriculture is intimately linked to climate conditions and therefore highly exposed to climate change. Short-term natural extremes such as storms and floods, inter-annual to decadal climate variability (such as the El Niño) have significant effects on crop and pasture production (Tubiello, 2005).

The climate system is already moving beyond the patterns of natural variability. The extreme drought and heat wave that hit Europe in the summer of 2003 caused a crop yield decline by 20-30 % and a green fodder deficit up to 60 % (in France). In Switzerland fodder had to be imported from as far away as Ukraine. The risk of summers as warm as 2003 may increase by two orders of magnitude in the next 40 years in Europe (Stott *et al.*, 2004). The atmospheric conditions that result in such heatwave conditions are thus likely to increase in frequency (Meehl and Tebaldi, 2004) and may approach the norm by 2080 under high emission scenarios (Beniston, 2004; Schär *et al.*, 2004). Global climate change can therefore be expected to threaten food supply through changing patterns of rainfall and increasing incidence of extreme weather (Tubiello

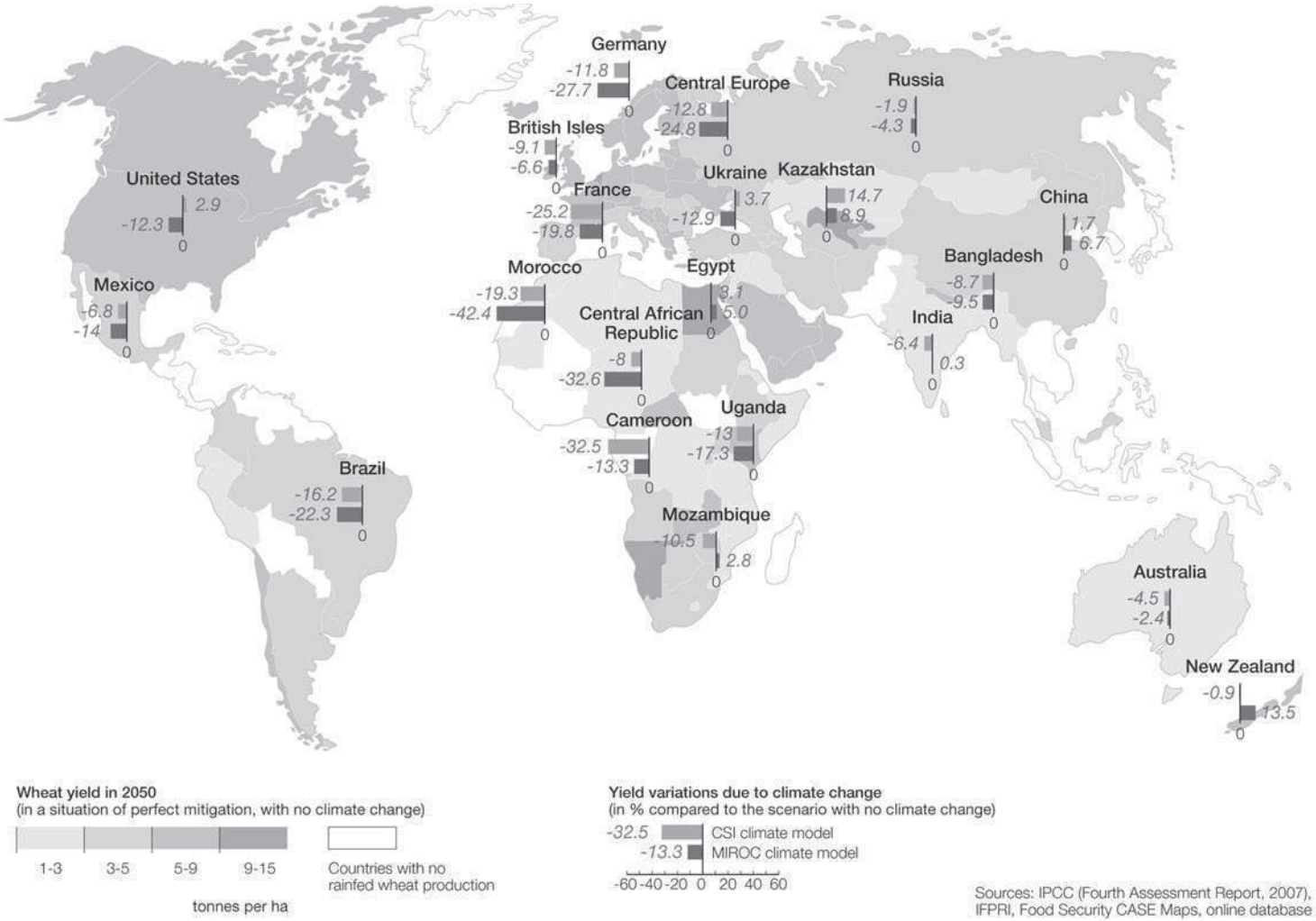


Figure 1. Wheat and climate change.

Compared to a baseline scenario of an increase in wheat yields due to technological advances, the simulation of the effects of climate change (for the IPPC A1B scenario, where greenhouse gas emissions increase until 2050 and remain significant until 2100), shows convergent results for significant reductions in expected wheat yields in many parts of the world (Europe, North and Sub-Saharan Africa, and Latin America), and increases in a very few situations, such as Central Asia. The magnitude of these variations is still uncertain, as shown by the differences between the two climate models used.

et al., 2007), leading to greater variability of production, increased price volatility and changes in trade flows (Lobell *et al*., 2008).

In arid parts of Africa, nomadic herders rely almost entirely on the meat and milk of their livestock to survive. They follow the rains and move their goats, sheep, cattle and camels across vast areas. Between 1980 and 1999, severe droughts have caused a mortality of national herds comprised between 20 and 60 % in several arid sub-Saharan countries (IPCC, 2007). Again, 70 percent of the cattle and sheep are estimated to have died in 2006 in parts (Somalia, Kenya and Ethiopia) of the Horn of Africa. Again, in 2009-2011, the worst drought in 60 years has triggered a looming humanitarian and food crisis, which would affect above 10 million people across the region.

Early warning signs suggest an impact of climate change on the yields of some major crops. Rice and wheat are the most important sources of calories for humans. Their production increased by ca. 30 % per decade in the 1980's. From 1997 to 2007, this rise in production was halved for rice and decreased to 1 % for wheat. Of the world's three most important grains, only maize maintained the rate of increase of the 1970s and 1980s into the most recent decade (Long *et al*., 2010). Since two decades, a decline in the growth trend of cereal yields is observed in many European countries (Olesen *et al*., 2011). In France, from 1990 on, heat stress during grain filling and drought during stem elongation have counteracted yield increases achieved through genetic progress (Brisson *et al*., 2010). This is consistent with statistical modelling showing that global wheat and maize production declined since 1970 by 5.5 and 3.8 %, respectively, compared to a counterfactual without climate trends (Lobell *et al*., 2011).

Increased frequency of heat stress, droughts, and floods negatively affect crop yields and livestock production beyond the impacts of mean climate change, with impacts that are larger and occurring earlier than predicted using changes in mean variables alone (IPCC, 2007b). It is highly likely (more than 90 % chance) that by the end of the XXIst century, growing season temperatures in most of the tropics and subtropics will exceed even the most extreme seasonal temperatures recorded from 1900 to 2006 (Battisti and Naylor, 2009). Unless major adaptations are made, high seasonally averaged temperatures will challenge food production in the future. Indeed, above-optimal temperatures have been reported to induce severe damages to corn and soybean crops in the U.S., leading to potential large negative impacts in the future (Schlenker and Roberts, 2009). Yield damaging temperatures spanning periods of just a few days for cereals and fruit trees affect particular developmental stages that condition the formation of reproductive organs, such as seeds and fruits (Wheeler *et al*., 2000; Wollenberg *et al*., 2003).

During the XXth century a major drought index has increased over a number of regions, including Southern Europe and most of Africa (Bates *et al*., 2008). A further drying of large parts of the subtropics is likely by the end of this century (IPCC, 2007a). Amplification of the hydrological cycle as a consequence of global warming is forecast to lead to more extreme intra-annual precipitation regimes characterized by larger rainfall events and longer intervals between events (IPCC, 2007a). More extreme rainfall regimes are expected to increase the duration and severity of soil water stress as intervals between rainfall events increase (Knapp *et al*., 2008). In the long run, heat and drought can trigger desertification, as a decline in vegetation cover increases soil erosion and run-off further reducing soil water storage. Drought in particular plays an important role in pasture dynamics and can lead to long-term degradation (Briske *et al*., 2005).

Over the last 30 years, hundreds of carefully managed experiments where soil nutrients were often non limiting have confirmed that plant biomass and yield tend to increase significantly as CO_2 concentrations increases above current levels. Carbon dioxide levels that will be reached by 2050-2070 have been shown to increase yields in the range of 10–20 % for crops from temperate origin (C_3 crops, like wheat and rice) and 0–10 % for crop species of tropical origins (C_4 crops like maize) (Tubiello *et al*., 2007). It is important to note though that the effects of elevated CO_2, as measured in experimental settings and subsequently implemented in models, may overestimate actual field and farm-level responses because of interactions with many limiting factors such as high temperatures, low nutrient concentrations, droughts, pests, weeds and air pollutants (Soussana *et al*., 2010).

We still do not know how much of the carbon dioxide fertilizing effect will remain under these complex conditions adding up to the many uncertainties for the future supply of food. Moreover, ozone concentrations in future decades, with or without CO_2, with or without climate change, will negatively impact plant production, possibly increasing exposure to pest damage (Tubiello *et al*., 2007).

Climate change influences the occurrence, prevalence and severity of plant diseases (Kersebaum *et al.*, 2008). For example, the appearance of a black rot fungus in Northwestern Europe fruit trees is best explained by rising temperatures during the vegetation period although this does not hold for other fruit rot species (Weber, 2009). Under future climate conditions, there is a risk that the European corn borer establishes permanent populations in Central Europe therefore extending its climate niche to cover almost the entire area suitable for agriculture by 2040-2075. High temperatures (above 32°C) have also been reported to enhance weed competitiveness in soybean crops (Tungate *et al*., 2007).

Sixty per cent of human epidemics are caused by animal pathogens found in the wild or in domestic flocks. 2010 was the year of the eradication of rinderpest, an infectious disease that has decimated cattle for millennia. Nonetheless, in recent years, several vector-borne, parasitic or zoonotic diseases have (re)-emerged and spread in with major health, ecological, socio-economical and political consequences. Climate change is already affecting the spread of animal diseases such as the bluetongue virus, a sheep disease that is moving north into temperate zones of Europe (Artz *et al*. 2010). There is some evidence that climate change and especially elevated temperatures, have changed the overall abundance, seasonality and spatial spread of endemic helminths in the U.K. affecting animal health and welfare (van Dijk *et al*., 2010). In Europe, the primary arthropod vectors of zoonotic diseases are ticks, and there is also good evidence that ticks distributions have changed because of habitat fragmentation and climate warming (Gilbert, 2010).

Warming also has direct impacts on livestock. The onset of thermal stress in livestock often results in voluntary declines in physical activity with associated declines in eating and grazing activity. High temperatures put a ceiling to dairy milk yield from feed intake. This can induce an energy deficit and decrease cow fertility, fitness and longevity (King *et al.*, 2005). Increases in air temperature and/or humidity have been shown to affect conception rates of domestic animals that are not adapted to these conditions. This is particularly the case for cattle, in which the primary breeding season occurs in the spring and summer months.

Projections of regional climate change impacts

At the regional scale, climate change impacts are likely to vary widely and to lead to changes in the distribution of cropping areas as shown by the example of Europe. In northern Europe, increases in yield and expansion of climatically suitable areas are expected to dominate, whereas disadvantages from increases in water shortage and extreme weather events (heat, drought, storms) will dominate in southern Europe (Bindi and Olesen, 2011). In the southern Mediterranean, the likelihood of crop failure would rise sharply to more than 60 % (Ferrara *et al.*, 2010). Although in the UK for the 2050s, wheat will mature earlier in a warmer climate and avoid severe summer drought, the probability of heat stress around flowering that might result in considerable yield losses is predicted to increase significantly (Semenov, 2009). In the northernmost agricultural areas of Europe and Russia, climate change is projected to result in milder winters, which may enable cultivation of winter crops to a greater extent. However, fluctuating conditions that currently hamper wheat overwintering, may be exacerbated in the future by increased climatic variability and extreme weather events (Peltonen-Sainio *et al.*, 2010). This could delay the adoption of winter-sown crops (cereals and rapeseed) for several decades.

Climate change is moreover projected to have detrimental impacts on winegrowing in southern Europe, mainly due to increased dryness and cumulative thermal effects during the growing season. Conversely, in cooler areas of western and central Europe, projected future changes will benefit not only wine quality, but might also delineate new potential areas for viticulture, despite some likely threats associated with diseases (Malheiro *et al.*, 2010).

Climate change adaptation

Agricultural systems need to change in the face of climate risks. In order to stabilize outputs and income, production systems must become more resilient, *i.e.* more capable of performing well in the face of disruptive events. Farmers already adapt to climate warming through changes in agricultural practices (*e.g.* sowing dates, harvest dates, animal stocking density, fertilization…) and changes in plant seed and animal breed mixes. This autonomous adaptation is likely to have substantial benefits under moderate climate change for some agricultural systems. Enhancing the capacity to manage climate risk is also a core adaptation strategy. There are many region- or situation-specific climate risk management options (*e.g.*, crop and livestock diversification) that may also have adaptation value (Howden *et al*., 2007).

Smallholder, crop, livestock and pastoral subsistence systems, especially those located in marginal environments, are often characterized by livelihood strategies that have evolved (*i*) to reduce overall vulnerability to climate shocks (adaptive strategies), and (*ii*) to manage their impacts *ex-post* (coping strategies) (Morton, 2007). Risk sharing strategies within families and rural communities, as well as insurance mechanisms need to be strengthened to reduce vulnerability.

Under more severe climate changes, there are limits to the effectiveness of autonomous adaptation and planned adaptation is needed (Howden *et al*., 2007). Planned adaptation in agriculture will require a large coordinated international research effort to develop seeds and breeds adapted to the unchartered climatic conditions of the end of this century and to design resilient and eco-efficient crop and livestock systems, while ensuring the dynamic conservation of soil, water and genetic resources.

Agro-ecological engineering through the increased use of genetic and species diversity at field and landscape scales and eco-technologies to adapt water management by improved water harvesting and increased water use efficiency, to monitor and reduce greenhouse gas, to increase and verify soil carbon stocks will play a key role. Investments in crop and animal disease protection and in invasive species monitoring will be required to preserve plant, animal and human health. Remote sensing and information technologies, like seasonal weather forecast, the geo-monitoring of crops and precision agriculture have the potential to reduce inputs while increasing productivity and resilience. However, the results of adaptation will be a function of both the likely technical effectiveness of adaptations and their adoption rate. Both factors are restricted in some tropical regions by poverty and hunger, lack of financial resources, environmental degradation and conflicts.

Climate change mitigation

Global greenhouse gas (GHG) emissions due to human activities have grown since pre-industrial times, with an increase of 70 % between 1970 and 2004. Without mitigation, the concentration of carbon dioxide in the Earth atmosphere may reach approximately 1,000 parts per million (ppm) by the end of the present century and remain above this level for thousands of years. In this business as usual worst case scenario, by the end of this century, global average temperatures would rise by more than 5°C, with regional rises of more than 10°C, and will continue to rise for centuries, reaching levels well above tipping points for most ecosystems and agricultural production systems (Schneider, 2009). Sudden and severe declines in crop yields would lead to large numbers of refugees, threaten food security and ignite conflicts in a number of world regions.

Humans have a great influence on the global carbon cycle and utilise about 40 % of the earth's net primary production (Rojstaczer *et al*. 2001). Globally, about 2,150 Gigatons of carbon are stored in plants and soil. A fraction of this amount could be released in the next century through climate change and land use change, which would in turn again accelerate climate change. Preserving soil carbon stocks through careful soil management will therefore be required to avoid positive feedbacks on global warming (Ciais *et al*., 2005). In addition to reducing its own emissions, carbon

sequestration in agricultural soils can play an important role in offsetting emissions from other sectors.

In 2004 agriculture directly contributed about 14 % of global anthropogenic GHG emissions in CO_2 equivalents. Land use, land use change and forestry account for a further 17 % (IPCC, 2007). In order to limit future global warming to a 2°C temperature increase rail guard, anthropogenic GHG emissions will have to decrease globally by at least 50 % by 2050 from 1990 levels. Agriculture is not currently subject to emissions caps, although several countries are already implementing mitigation action plans.

Quantifying GHG emissions from agricultural activities is complex. First, the atomistic nature of production (many individual farmers) in a wide range of geographic and climatic conditions means that emissions are not only highly variable but also difficult and costly to measure precisely. Second, there continues to be a great deal of scientific uncertainty as GHG emissions from agriculture are subject to a complex interplay of many factors such as climate, soil type and production practices.

Many agricultural practices can potentially mitigate GHG emissions, the most prominent of which are improved cropland and grazing land management and restoration of degraded lands and cultivated organic soils (Smith *et al*., 2008). Reducing excesses of nitrogen fertilization and substitution of mineral N fertilizers by biological N fixation, as well as improved nutrition of domestic ruminants to reduce methane from enteric fermentation and improved manure management can play a significant role. Lower, but still significant mitigation potential is provided by water and rice management and agroforestry (Smith *et al*., 2008).

The global technical mitigation potential from agriculture (excluding fossil fuel offsets from biomass) by 2030, considering all gases, is estimated to be approximately 5500-6000 Mt CO_2-eq per year, with half of the potential that could be reached in theory for carbon prices up to 50 US $ per ton of CO_2-eq (IPCC, 2007). In addition, GHG emissions can be reduced by substitution of fossil fuels for energy production by agricultural feedstocks (*e.g.* biogas from crop residues and dung) and by dedicated energy crops such as highly productive perennial grasses and short rotation coppices. The economic mitigation potential of biomass energy from agriculture is estimated to be of the same order of magnitude as that of direct GHG mitigation in agriculture (Smith *et al*., 2008).

However, accounting for the indirect land use changes arising from agricultural production is another important challenge. In particular, the links between production of biofuels from food crops (in many cases subsidized), consequent land use changes, and the rise in food prices demonstrate the importance of foreseeing the range of consequences. Biofuel expansion on arable lands leads to land use changes including deforestation and hence to indirect emissions of carbon dioxide that were estimated to be large in some studies (Searchinger *et al*., 2009). Some agricultural GHG mitigation options are cost competitive with a number of non-agricultural options in achieving long-term climate objectives. Such options should not reduce agricultural productivity, but rather improve the eco-efficiency of agricultural systems by reducing GHG emissions per unit of crop and animal products.

Food security under climate change

The 1996 World Food Summit held under the auspices of the Food and Agriculture Organization (FAO) defined food security as a 'situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life' (FAO, 2002). This definition comprises four key dimensions: availability, stability, access, and utilization of food.

The first dimension relates to the overall ability of the agricultural system to meet food demand. The second dimension, stability, relates to the risks for individuals of temporarily or permanently losing their access to the resources needed to consume adequate food. An important cause of unstable access is climate variability. The third dimension, access, covers entitlements by individuals to

adequate resources, which encompasses purchasing power, land tenure rights and traditional rights of rural people to a share of common lands.

Millions of people are undernourished and hungry because of a lack of access to sufficient food. They are predominantly located in rural areas in the tropics (Ravallion *et al*., 2007, IFAD *in* Morton) and their vulnerability is increased by socioeconomic, demographic, and policy trends limiting their capacity to adapt to climate change (Morton, 2007). Among the rural food insecure, most consume more calories than they produce in their fields and are therefore also hurt in the short term by price increases. As the poorest areas slowly become more integrated with markets, they are likely to improve overall incomes and productivity, at the cost of becoming more vulnerable to price shocks.

Finally, utilization encompasses all food safety and quality aspects of nutrition, including the sanitary conditions across the entire food chain. Even net producers of food are often consuming insufficient calories, choosing instead to spend some of their income on sugar, meat, and other more expensive foods (Naylor and Falcon, 2010). Food quality may be affected by climate change, as for instance cereal and forage crops show lower protein and micronutrients concentrations under elevated CO_2 conditions (Easterling *et al*., 2007). Food safety at all stages from production to consumption is also affected by climate change, which creates increased risks of transmission of some key food pathogens (*e.g.* salmonellas) (Miraglia *et al*., 2009).

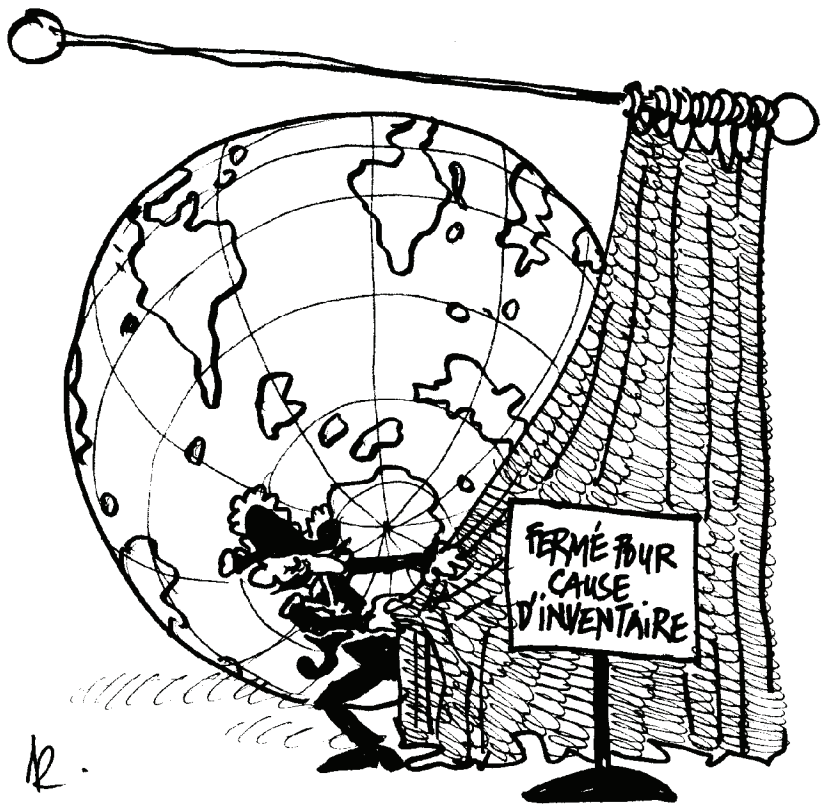
By using storylines, climate and crop models, a range of plausible futures was studied by IFPRI (2010) suggesting that the first half of the XXIst century is likely to see increases in real agricultural prices. The rise in food demand driven by population growth and increasing affluence would exceed that in food supply given negative impacts of climate change. With climate change, price increases would range from 30 percent for rice in the optimistic scenario (with high income growth and low population growth) to 100 percent for maize in the baseline scenario (with moderate income and population growth). In the unlikely event that perfect greenhouse gas mitigation (a continuation of today's climate in the future) is achieved, the rise in cereal prices would be halved.

Further impacts on food security were also shown in this IFPRI study. Climate change worsens future human well-being, especially among the world's poorest people, increasing the number of malnourished children relative to a world with perfect mitigation. With high per capita income growth and perfect climate mitigation, calorie availability in low-income countries could reach almost 85 percent of that in developed countries by 2050. In contrast, under the pessimistic scenario, calorie availability – and human well-being more generally – declines in all regions unless climate change if fully mitigated.

Towards climate smart food systems

Climate smart agriculture has been defined as agriculture that sustainably increases productivity and resilience (adaptation), reduces greenhouse gases (mitigation), and enhances food security and development (FAO, 2010). A sustainable intensification of agriculture, that would allow to close yield gaps and to increase biological efficiencies, especially in developing countries, can enhance food security and contribute to mitigating climate change by stopping deforestation and the expansion of agriculture into sensitive ecosystems. More productive and resilient systems may also lead to beneficial side effects in terms of carbon sequestration and reduction of greenhouse gas emissions per unit product. These multiple win-win options require changes in the management of biodiversity and natural resources (*e.g.* soil conservation and restoration, water harvesting and saving, increased use of biological nitrogen fixation and of integrated systems such as agroforestry and crop-livestock, *etc*…). However, win-win options are currently limited by gaps in our understanding, as well as by a number of economical and institutional barriers.

Changes in diet preferences and in bioenergy policy may also help in reaching climate smart food systems. For instance, shifting grain-fed beef consumption to poultry, pork or pasture-fed beef and not using food crops as biofuel feedstocks would significantly enhance food availability and reduce



Drawing by Robert Rousso *in le Courrier de l'environnement de l'INRA* nº 40.

the environmental impacts of agriculture (Foley *et al*., 2011). Moreover, improving food storage and transport in developing countries to reduce post-harvest losses and in industrialized countries avoiding wastes at the consumer or retail level would reduce the excessively high (ca. 40 %) level of food losses and wastes. Climate smart food systems will therefore require a combination of changes at all steps of the planetary food web ranging from a better management of natural resources by resilient farming systems to improved education of consumers, through changes in storage, transport, processing and retailing infrastructures.

Reinvesting in agriculture and in food systems will require substantial funding as well as changes in trade and regulatory arrangements to limit price volatility, increase market transparency and favour international cooperation in agricultural development and rural environment protection.

Conclusion

Humanity is now ruling to a large extent the fate of the global biosphere and is confronted to crucial choices concerning its future. A continued development will depend upon our capacity to steward the biosphere by halting greenhouse gas emissions and managing ecosystem services and biodiversity to operate world food systems in a safe space. This will also require a sustained economical growth and welfare redistribution that would lead to a rapid increase of per capita income, to a stabilization of the world population and to an improved global food security. Passing this crucial test of being able to fill the Earth and govern it sustainably, will require satisfying every man's need, but not every man's greed.

Therefore, policies should aim at (IFPRI, 2010): i) rising poor people's incomes and access to food, knowledge and natural resources to achieve sustainable food security and resilience to climate

change; ii) investing in climate smart agriculture, consumers education and waste reduction to enhance sustainable food security; iii) revisiting international trade arrangements to compensate for different climate change effects in different locations and iv) cutting greenhouse gas emissions and planning adaptation to minimize the harmful effects of climate change on food security.

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Food losses and wastage – crucial, complex and multiple reserves for sustainability[1]

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A little known subject of increasing interest

The increasing world population, the perception of the finite supply of arable land, the affirmation of the right to food and the increase in agricultural product prices are all aspects that place human food consumption at the forefront of political and social concerns. The FAO estimates that to ensure food security for a world population of 9 billion humans (expected by 2050), agricultural production must increase by 70% (Bruinsma, 2009). However, biological and agronomical constraints, the vagaries of nature and societal demand already significantly restrict production. Other elements such as global warming and rapid urbanisation in southern countries mean that our food systems must innovate in order to adapt.

While agriculture has been confronted with the pressing demand to increase production, the reduction in post-harvest losses and wastage is today considered to be an environmentally responsible, economical lever (Lundqvist *et al.*, 2008; Nellemann *et al.*, 2009; Gustavsson *et al.*, 2011) for increasing food availability. A British foresight study considers that cutting by half losses and wastage along the entire food chain globally would enable to save food resources equivalent to 25% of current agricultural production in the future (Foresight, 2011).

The considerable extent of losses and wastage, estimated at around 30% of agricultural production worldwide (Lundqvist *et al.*, 2008; Foresight, 2011; Gustavsson *et al.*, 2011), is not compatible with a sustainable approach to food systems. Throughout the production-processing-distribution chain and even in households, wasted food has consumed energy and water, has occupied land and labour, has generated pollution without even serving its main purpose, that of providing nourishment to humans. Furthermore, food waste collection, processing and disposal is a source of greenhouse gases. The British body WRAP[2] considers that food losses and wastage by households alone has consumed 6% of water requirements in Great Britain and was the cause of 3% of national greenhouse gas emissions (WRAP and WWF, 2011).

The phenomenon raises social and ethical questions given the ever scandalously high portion of the food insecure population, in southern countries, but not solely (FAO, 2010). Finally, food losses

1. This text is based on a previous work published *in:* Esnouf C., Russel M., Bricas N. (Eds.), 2011, *duALIne – Durabilité de l'alimentation face à de nouveaux enjeux. Questions à la recherche,* Report Inra-CIRAD, 112-129. INRA, Paris, France, *http://www.inra.fr/l_institut/prospective/rapport_dualine*

2. *Working together for a world without waste*, non-profit organization for the reduction of waste, efficient use of resources, and development of sustainable products.

and wastage have a cost, individually, for those causing them, and collectively, for society which bears them.

Unawareness of the quantities of food losses and wastage, of the mechanisms in play and of the role of the many stakeholders mean that we should refrain from applying reduction measures in a hasty and non-concerted manner. Losses and wastage are not related to stakeholders' carelessness. In northern countries, they are the visible result of food systems undergoing profound socio-economic changes (market globalisation, process industrialisation, hygiene regulations…), of changes in lifestyle and in related values (value of time notably). In southern countries, post-harvest losses indicate the failure in the daily battle of millions of farmers to protect their crops. Despite the projects and an ambitious programme of the FAO, *Prevention of food losses*, implemented further to the World Food Conference in 1974, the subject is not less topical or relevant today. However, it took on a new dimension at the turn of the millennium, when our modern and opulent societies have become aware of the colossal quantities of perfectly edible food wasted.

The entrance, or return, of food losses and wastage on the political agenda[3] only marks the beginning of the hard work to be undertaken in order to analyze their causes and consequences, and to identify existing obstacles and the means to overcome them in order to reduce the extent of the phenomenon.

What is loss and what is wastage?

Definitions exist for the terms losses and wastage. It is necessary to recall them to effectively describe these issues:
– *losses*, according to the FAO (1981), refer to "total modification or decrease of food quantity or quality which makes it unfit for human consumption". Food losses can therefore be quantitative – expressed in weight and monetary value – and qualitative – expressed in health or nutritional terms, in terms of cleanliness or purity, *etc.* (Tyler and Gilman, 1979).
– *wastage* is the "deliberate discarding and throwing away of food that is fit for purpose and perfectly good to eat" (Lundqvist *et al.*, 2008).

In southern countries we often hear of post-harvest losses, that is to say losses occurring from the harvesting to distribution stages. The term wastage, and more frequently used but less precise food waste, rather applies downstream of the food chain, in distribution, catering and households. How these terms are used, however, depends on a simplified conception of food systems that are far more complex in reality, as upstream losses, during the first stages of the chain, also exist in northern countries, but for different reasons and under different names (market withdrawal, shrinkage[4]). Strictly speaking, the term waste, governed by a European directive[5], refers to what is thrown away without distinction of the circumstances and reasons which lead to the product discard.

A number of reasons lead to losses or wastage at all stages in food systems, as much in northern countries as in southern countries. Table 1 gives a non-exhaustive view of these reasons.

3. Resolution of the European Parliament on how to avoid food wastage voted on 19 January 2012: *http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+REPORT+A7-2011-0430+0+DOC+PDF+V0//EN*

4. Loss of volume or weight in certain types of merchandise during manufacture or transport.

5. Directive 2008/98/EC of European Parliament and of the Council of 19 November 2008 on waste *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF*

Table 1. Main causes and locations of food losses and wastage in food systems in northern and southern countries.

Stage in the food system	Northern countries	Southern countries
– at harvest	Non-harvest, market withdrawals and destruction (fruits and vegetables)	Tools, accidents, pests, limited access to the field
– at storage (at farm, warehouse *etc.*)	Temperature, humidity, dehydration, market withdrawals	Pests, lacking cold chain, recipients and packaging
– at transport (at several stages)	Packaging, temperature, handling	Accidents, road blocks, lacking infrastructure, vehicles
– at processing (primary, secondary *etc.*)	Shrinking, process-related losses, standardization	Tools, accidents
– at distribution (markets, shops *etc.*)	Refusals and returns, nearing use-by date, damage, mis-storage	Marketing standards of supermarkets and export markets?
– at consumption (at home, out of home)	Confusion between use-by date and best-before date, poor household management and knowledge, unsuitable portions, hygiene	Changing household practices of wealthy households towards those in industrialized countries?

Source: compilation by authors.

Problem of distinctness

Loss or wastage? The wide variety of situations in which they occur makes it difficult to clearly distinguish between the two phenomena. What is wastage for some is considered loss for others. It may be a question of view point depending on regulatory context, financial constraints (cost of staff or equipment) or cultural practices. The term wastage bears a moralistic connotation and implies guilt, which conceals the fact that in many cases stakeholders only apply the standards of modern food systems such as hygiene regulations for example. It has to be noted, however, and surveys on domestic food waste underline it (Eurobarometer 2011, WRAP 2007), that stakeholders of food supply chains, including households, are neither aware of throwing food away nor aware of the scale that such waste represents in our societies.

For these reasons we prefer to use the term food losses and wastage together without distinguishing them.

Multiple uses of agricultural resources little taken into account in the concept of losses and wastage

Apart from their differences, these definitions question the relationship between the use of agricultural resources for human diet and their other multiple uses, and the way this relationship is taken into consideration in this paper. Certain authors relate in a more or less explicit way crops intended for animal feed to losses and wastage (Stuart, 2009; Lundqvist *et al.*, 2008), whereas others relate high consumption of animal products to a wastage of farmland or nitrogen (Sutton *et al*., 2011) in the case of certain farming methods. In the same way, the increasing use of agricultural raw materials as biofuels sparks debate on wastage of resources with respect to meeting food requirements. If we consider losses and wastage to include foods that would initially have been edible to humans, but which have served a different purpose (chemistry, farming, energy…), we observe very high quantities. However, if we take into account the final purpose of by-products, we achieve a more interesting systemic typology. Most agricultural products are broken down and separated into components, distinguished according to their profit-making nature as main products, by-products and

waste[6], and used in multiple economic sectors: human food chain and animal feed, chemical, pharmaceutical and cosmetic industries, leather goods and textiles, energy production or compost to cite the main sectors. Thus everything is interlinked. What humans do not directly eat is not necessarily lost or wasted.

Difference between edible and non-edible to clarify wastage

Naturally, agricultural and livestock products are not entirely edible for humans, in any case not in normal conditions (citrus fruit zest, bones, egg shells *etc.*). This being said, the line between what is edible and what is not edible is sometimes fine and depends on dietary habits and food culture (consumption of bread crusts, apple peel, fat on meat *etc.*). Therefore food processing and kitchen waste contains a non-edible fraction which is neither loss nor wastage for the human diet. The lack of precision leaves room for confusion between the terms food wastage or waste and bio-waste, confusion that the European Parliament pointed out recently[7].

In order to be as accurate as possible with regard to the various constructs, Gustavson *et al.* (2011) defined as food losses and waste "the masses of food lost or wasted *in the parts* of food chains *leading* to "edible products going to human consumption"". Only agricultural resources meant for human consumption that are not consumed, regardless of the reasons and regardless of the fate of the products (animal feed, compost, *etc.*), are considered to be lost or wasted, according to these authors.

The lack of consensus as to the definition of the terms losses and wastage or waste is problematic as firstly, the subject even about which public and private stakeholders discuss is neither well identified or identical among these stakeholders, and secondly, it may partly explain the significant variations according to source between the estimated amounts of lost and wasted food.

Regardless of the definition, accurate and representative data on the quantities and on the value of food losses and wastage is missing in most countries. Nothing is known on the subject either in large emerging countries (China, India or Brazil) or in the megalopolis of the South in which food systems are about to become westernized (diversification of distribution channels with penetration of supermarkets; industrialisation of supply chains; diet changes). Is the type of losses becoming similar to that in northern countries? Due to the lack of available studies, our analysis does not include the losses and wastage in urban distribution systems in these countries.

Extent of losses and wastage in the world

Several sources estimate global food losses and wastage at around 30 % of initial production intended for human consumption (Lundqvist *et al.*, 2008; Foresight, 2011; Gustavsson *et al.*, 2011). On the basis of literature and FAO food balance sheets, per major world region, Gustavsson *et al.* (2011) established that between 208 and 300 kg of food per head and per year is lost or wasted throughout the food supply chain in European and North American countries, of which 95 to 115 kg by consumers. In sub-Saharan Africa and South and South East Asia, 120 to 170 kg of food per head and per year is lost or wasted, of which only 6 to 11 kg by consumers (fig. 1).

6. Directive 2008/98/EC of European Parliament and of the Council of 19 November 2008 on waste *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF*

7. *http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+REPORT+A7-2011-0430+0+DOC+PDF+V0//EN*

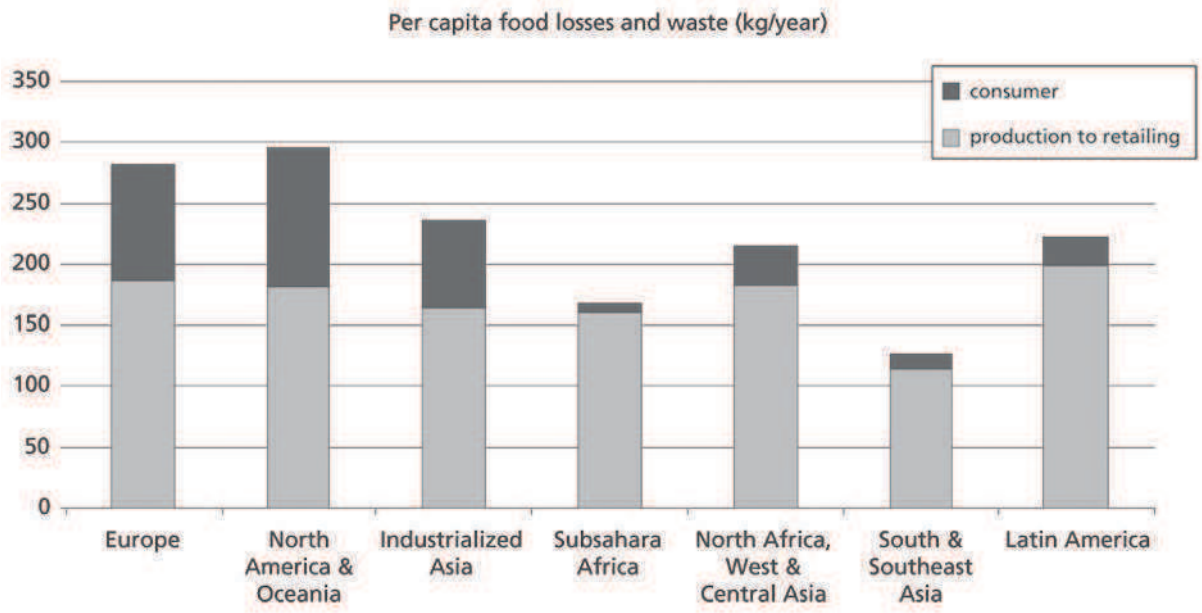

Figure 1. Food losses and wastage per head and per year (kg/year), at consumption stage and upstream of the food supply chain, in various regions of the world. *Source:* Gustavson *et al.*, 2011.

Northern countries

Surveys on households have analyzed domestic food losses and wastage. In the United States, according to Jones (2004), each household wastes 14% of the weight of its food purchases, equivalent to 589 dollars per year. In Great Britain, 25% of quantities purchased are wasted, representing 480 pounds sterling per year and per household, according to data from the WRAP (2009). This data reports 8.3 million tonnes, equivalent to 134 kg per person, of food and beverages wasted per year, of which the two thirds could have perfectly well been consumed. Not all products are concerned in the same way: loose or wrapped fruit and vegetables, bread, ready meals, meat, fish and milk are top of the list. After several years of awareness-raising campaigns, the WRAP (2011) tested their effectiveness in a new survey: in 2010, food waste in British households had dropped, in particular of edible foods (-18%).

In France, according to a study by the Environment and Energy Management Agency (Ademe, 2007) conducted on the composition of household and jointly collected waste, 7 kg of wrapped foodstuffs are wasted per year and per head. Thirteen kilograms out of the 72 kg of food thrown away represent leftover meals or other foodstuffs, bringing the quantity of food wastage per head and per year to 20 kg.

In the agrifood industry in France, the survey by the Network of professional and interprofessional organisations for the safety and quality of animal foodstuffs (RESEDA, 2005) shows that the entire primary processing sector of crops (notably sugars and fats, starch and flour mills) puts its by-products (9.5 million tonnes of dry matter) to use in animal feed. Animal processing industries face more difficulties in using their by-products (0.55 million tonnes): two thirds of this waste, representing almost 0.3 million tonnes of meat meal, is incinerated since the bovine spongiform encephalopathy (BSE) epidemic[8]. The remaining third is processed into gelatine and glues.

Only one British study (WRAP, 2010) discusses food waste in the manufacturing, retailing and upstream distribution sectors (national and regional distribution centres, wholesalers, cash and carry outlets).

8. Today, twenty years after the first BSE crisis, and in the light of screening test results, the European Commission and the Member States are leaning towards gradual reintroduction of certain processed animal proteins in the feed of non-ruminant animals.

Table 2. Quantity of household waste, packaging waste and other waste generated between manufacturing and household consumption in Great Britain (WRAP, 2010).

	Total waste in tonnes per year			
Stage in the food supply chain	Food	Packaging	Others	Total
Manufacturing*	2 591 000	406 000	2 019000	5 016 000**
Distribution centres, wholesalers, cash and carry outlets	4 000	85 000	9 000	98 000
Retail	362 000	1 046 000	56 000	1 464 000
- sub-total	**2 957 000**	**1 537 000**	**2 084 000**	**6 578 000**
households	8 300 000***	3 600 000	20 566 000	32 466 000
Total	**11 257 000**	**5 137 000**	**22 650 000**	**39 044 000**

* not including primary processing of agricultural raw materials.
** not including 2.2 million tonnes of by-products used in animal feed.
*** including beverages disposed of in sewers.

According to this study (table 2), manufacturing as a whole generates the highest volumes of food waste after households, equivalent to almost 2.6 million tonnes per year, and this despite the fact that by-products used elsewhere are not included in the figures. According to occasional observations reported by WRAP (2010), losses and wastage in agri-food industries may represent up to 20 % of processed raw materials. In lower proportions, the bulk of food waste in the distribution field is generated in the retail sector (362,000 tonnes per year). FareShare, the British food banks federation, declares to have saved only 3,000 tonnes of foodstuffs in 2008 (compared to 2,000 tonnes in 2007).

In France, only 50,000 tonnes of food was donated to charity in 2010 – figure to be compared to the 600,000 tonnes that food banks say are withdrawn from supermarkets each year, and of which 200,000 tonnes would be perfectly edible and recoverable (Sita France, Banque alimentaire du Bas Rhin, 2011).

Catering is also a sector which generates significant amounts of losses and wastage. Health institutions and medico-social establishments are especially affected. A British study assessed a plate waste rate at 19 % to 66 % per ward, according to how the ward was managed (tray or trayless) (Sonnino, McWilliam, 2011). An estimation made by the hospital in Le Mans, France, observed losses and wastage at 264 g on average per person and per meal (MAAPRAT, 2011), with hospitals producing twice as much as retirement homes. Standard management of catering little suited to the needs of patients and strict hygiene requirements can explain such high levels.

In school catering, a study sponsored by the Ministry of Agriculture and Food revealed that 150 g food was wasted per head and per meal (MAAPRAT, 2011). The difficulty in evaluating numbers of guests, the too large portions served, poor taste quality and surrounding catering conditions (time available for lunch, noise *etc.*) favour tray waste, which weighs much heavier than kitchen waste.

Southern countries

In southern countries, post-harvest losses remain little quantified to date, even though the international community became aware of the extent of the phenomenon in the 1970s. At the time, post-harvest losses were only related to storage and were synonymous with “damages caused by insects”. Various determinants such as the storage method, the choice of variety, the technical equipment, and finally the know-how and culture-based decisions remained underestimated. Taking the

example of corn, weight losses may vary from 3% for traditional varieties to more than 20% for hybrid varieties (Schulten, 1982).

For some years now, the FAO and its research and development partners have been investing in the compilation of databases on post-harvest losses (insert 1). Data collection meets the concern to provide representative and quality data, as in the past, a number of studies suffered from quantification and generalisation errors, and did not take into account the climatic, bio-physical and technical conditions of the situations studied.

Parfitt *et al.* recently attempted a state-of-the-art review (2010) and were confronted with the same lack of data as us: sources available mostly dated back to the 1980s and early 1990s, only covered rural areas and were of variable quality. Generally, data in literature and in information systems only covers losses of quantities, expressed in weight and/or, more rarely, in monetary value.

Insert 1. Two information networks on post-harvest operations and losses in southern countries

The Aphlis database, backed by the European Commission's Joint Research Centre and the Natural Resources Institute (NRI), contains data on cereal crops in South and East Africa. On the basis of literature and according to local post-harvest system experts, Aphlis provides loss estimates taking into account post-harvest operations, climatic zone, farm size and other factors. In the long-term, this database will integrate other products (pulses *etc.*) and other geographical areas (West Africa, Asia, Central and South America).

Another database, INPhO (*http://www.fao.org/inpho*), backed by the FAO, the Cirad and the GTZ, hosts a wide range of documents on post-harvest operations. It covers post-harvest systems for staple cereals (corn, rice and sorghum) and cassava in countries in Asia, Africa and Latin America. A broad range of technical information on post-harvest operations, on the physico-chemical and nutritional composition of products, along with recipes, is provided with the aim of supporting the development of activities in the tropical products sector.

For rice, the second most frequently consumed cereal by humans and of which losses have been widely studied, global losses are estimated at 15% (Grolleaud, 2002, Liang *et al.,* 1993), but variability between countries, climatic zones and practices and in data reliability is significant. During storage, often studied specifically, losses range from less than 1% in a study conducted in Malawi (Singano *et al.*, 2007) to 12-13% in Bangladesh (World Bank, cited by Grolleaud, 2002) through a bracket of 3-6% in China (IDRC, cited by Grolleaud, 2002) or in Malaysia (FAO, 2007).

In subsaharian Africa, cereal post-harvest and pre-processing losses are estimated at 10-20% in Aphlis, representing 4 billion dollars. Such losses represent 13,5% of the total value of cereal production in these countries (World Bank, 2011).

For perishable products (root vegetables, tubers, fruits, *etc.*), is even less representative data available. Losses of cassava in traditional systems in Africa may reach 45% (Jeon and Halos, 1991) and yam up to 50% (Osunde, 2008). As for fruits, post-harvest losses are considered to represent between 15 and 50% in southern countries in general (Subrahmanyam, 1986; Jeffries and Jeger, 1990; Coursey and Booth, 1972). In the Philippines for example they may range from 15 to 35% (from 30 to 60% for fruit such as the papaya). These figures are fairly representative of the average post-harvest losses recorded in the region by the Association of Southeast Asian Nations (ASEAN).

What lessons can be learned from the past and what action can be taken?

Even if accurate data on food losses and wastage is lacking in most countries in the world, global estimations suggest there is sizeable potential for reducing them. To use this potential, only global awareness, challenging food system organization as a whole and changing the behaviour of stakeholders concerned can be effective. Levers of action exist in northern and southern countries, but proactive public policy and in-depth research remain necessary to lend a wide scope to reduction measures.

Northern countries

In these countries, changes underway indicate a transformation in the representations and strategies of stakeholders, along with awareness of the need to address what is increasingly becoming a genuine "public concern".

The agricultural sector and certain agri-food industries are already exploring ways to reduce costs and minimize losses. A possible use of by-products for human food instead of animal feed is currently the subject of applied research. The agri-food industry is about to reinstate the principle of closed-loop supply chains, according to which the waste disposed of by one group serves as raw materials for another group.

Action levers exist for reducing food losses and wastage.

• *Technical levers*

In terms of technical innovations, significant progress has been made in the fields of production, logistics and storage. Production equipments enabling higher output have emerged, such as curd-cutting machines which save 3 % matter. It is also a question of improving process outputs by using a bigger variety of raw materials. At the interface between agri-food industries and distributors, production strategies, stock management and business practices must be further coordinated. Charities and waste collection professionals are beginning to set up networks for the redistribution and use of unsold goods. Packaging can also be improved: unit and portion size, sealing systems, reclosure systems to prevent products from drying out, hardening or spilling. Innovations can be expected in this area (National Packaging Council, 2011) and this as much as two thirds of packaging is used for foodstuffs. Rapid, accurate and little costly detection tests also need to be developed with respect to product safety to guarantee that waste prevention does not damage consumer health.

• *Fiscal levers*

Including donations in the calculation of the tax base of companies in France, recently authorised by law[9], has encouraged distribution to food banks. In the same way, increasing the charges on effluents loaded with organic matter has led companies to review their practices. At the Reseda colloquium in December 2009, a syrup-making company admitted to have saved 20 % of matter after having recalculated its water treatment charges upon renewal of its contract. As part of the Grenelle II law, the announcement for 2012 of compulsory separate collection of biowaste for large producers is already a driving force for innovation. In these sectors, we observe that it is often indirectly related decisions that initiate reduction measures of losses and wastage.

• *Normative or regulatory levers*

Expiry dates are often misunderstood and confounded. Whereas the use-by date applies to fresh products and refers to microbiological quality, the best-before-date applies to preserved or frozen products and to groceries and only refers to preservation of organoleptic properties and vitamin content. The debate on removing such dates has begun in the United Kingdom, and how they are used is currently being discussed at European level. Generally, hygiene regulations, the "zero risk" approach and penal responsibility for products are often brought up, notably in catering and supermarket distribution, as being major causes of losses and wastage. In Australia, an association which collects unsold goods, managed to obtain a regulatory text relieving supermarkets of all penal responsibility in the case of food intoxication caused by donated food, provided that associations guarantee to maintain the cold chain.

Inseparable from food safety concerns, image and consumer satisfaction are never sacrificed to concessions by companies. In contrast, companies even tend to establish increasingly wide safety margins, sometimes even more stringent than regulatory standards, as found out in the case of phytosanitary product residues (Waarst *et al.*, 2011). This is why relaxing regulatory constraints does not necessarily lead to a change in practices. In a similar way, lifting the EU restrictions (size and

9. *http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022521587&dateTexte=&categorieLien=id*

shape for example) for 26 out of 36 fruits and vegetables[10] in July 2009 visibly has not led to marketing of differently appearing products so far (Waarts *et al.*, 2011): the sector continues to rely on former standards as in-house quality standards. This means that entire sectors must adjust to relaxing regulations. Currently, processing equipment only operates with standard fruit and vegetables, and the logistics are less efficient for produce of different shapes and sizes which cannot be easily packed. Processing, logistics and marketing solutions must therefore be developed for the entire sector in order to create a market offer in compliance with the new standard.

• *Information and awareness-raising levers*

Initiatives of this type abound across Europe[11]. The British organisation WRAP works with partners from major businesses, trade bodies and local authorities and focuses on developing strategies of food waste prevention at consumer level, business and public sectors. The French Environment and Energy Management Agency (ADEME) set up the Optigède[12] website in June 2011, which offers an exchange platform for those in charge of waste prevention and management and provides information on best practices. Consumers are a prime target of information and awareness-raising initiatives, but other sectors become involved as well. School teaching and higher education is an appropriate means to introduce the subject of losses and wastage, as it covers a wide range of individual theoretical and practical educational subjects (hygiene, home economics, agri-food management, and environmental assessment).

Southern countries

In southern countries, forty years after the initial efforts undertaken by the FAO and its partners, post-harvest losses are still highly relevant. Technical innovations have been tacked on to traditional practices and local conditions. As little compatible, these innovations were the cause of losses at several post-harvest stages: choice of hybrid varieties vulnerable to pest attack, implementation of production seasons under less favourable meteorological conditions, too frequent and uncontrolled opening of airtight storage containers for grains in modified atmospheres. Considering the local context and involving the population by a participative approach are decisive factors for the success of crop protection measures. Action levers for reducing post-harvest losses lie in two main areas: technical innovations and organisational innovations (FAO and World Bank, 2010).

• *Technical innovations*

They are necessary at all stages in post-harvest systems. Among which:
– equipment for stabilising raw products (drying, salting, sweetening, smoking, fermentation, heat treatment), while aiming for technical efficiency in terms of yield, energy (renewable ideally) and environmental aspects, and while concentrating on the nutritional and sanitary qualities of products. Such treatments are likely to create added value and open perspectives to access new markets, for export for example. This equipment often requires little investment, and is accessible to small businesses and women's groups, which are priority targets.
– techniques and equipment are necessary both in households and in local companies (insert 2; FAO, 2008) in order to ensure airtight storage and transport, improvement in conditioning and packaging, in particular of perishable products (Manalili *et al.*, 2011), a cold chain based on traditional systems (underground cellars *etc.*), storage methods based on the use of bio-insecticides that are little harmful to human health and financially accessible, or based on integrated control, and this along with training in how to use the products.
– infrastructures for transport and packaging, vehicles, logistics resources.
– communication infrastructures (notably mobile telephones) for access to market information and for commercial operations.

10. *http://www.secteurpublic.fr/public/article/la-commission-autorise-la-vente-des-fruits-et-legumes-%C2%ABbiscornus%C2%BB.html?id=19812&C2=130&C6=&C1=105&C5=227*

11. For example the Danish movement *Stop Wasting Food http://www.stopspildafmad.dk/inenglish.html*, the British *Love Food Hate Waste http://www.lovefoodhatewaste.com/about_food_waste*; a website of the French federation of associations for the protection of the environment (FNE) *http://www.fne.asso.fr/fr/nos-dossiers/dechets/gaspillage-alimentaire.html*

12. *www.optigede.ademe.fr*

On-farm storage is important for household food security as it prevents farmers, lacking efficient storage equipment, from selling crops at low prices and from buying them back at high prices at a later date for their own consumption. Increasing storage capacity is therefore directly related to rural household food consumption, as much from a qualitative as quantitative view point.

Insert 2. PostCosecha: stimulating the economy by reducing losses

PostCosecha is a rural development strategy set up by the Swiss agency for development and cooperation in 1980, at Honduras first, then throughout Central America. It is based on simple and accessible technology, accepted by the population (mainly family-sized metal silos) and their manufacture on-site by local tinsmiths who also provide repair services and maintenance. The benefits of the project can be seen as much in households (food security and sanitary quality, domestic hygiene, women's work load, favourable trade conditions) as collectively (job creation, stabilisation of market prices, reduction of poverty, improvement in population living conditions) (Herrmann, 1991).

Since the success of PostCosecha (500,000 silos used in 2005), the FAO has been promoting the metal silo. It has been successfully distributed to 16 countries on three continents over the last ten years (FAO, 2008).

A similar experiment has been carried out in some African countries with a cowpea triple bagging system (Baributsa *et al.*, 2010). The bags have an airtight sealing system and are also made by local manufacturers.

http://www.postcosecha.net

• *Organisational innovation*

This can be valuable support. Dissemination of knowledge and access to capital, to equipment investment, to information and markets, which are all important for reducing losses, depend among other things on the way post-harvest operators and support services are organised. Producer organisations or cooperatives are therefore useful: joint specifications and standards can encourage adoption of best practices and increase the added value of products in a collective approach (Murthy *et al.*, 2009). Costly investments, such as a refrigeration system, can be shared (Centre technique de coopération agricole et rurale, 2011).

Access to a market, whether domestic or export, is an essential element to enabling operators to maximize their efforts. The Purchase for Progress (P4P) programme in the World Food Programme for example provides the most vulnerable farmers with access to markets and enables them to make durable investments by offering them favourable conditions for selling their cereal crops (direct contracts or contracts with local traders, three-year periods) (Davies and Salvignol, 2010).

Another essential element is access to capital which enables farmers and small operators to invest in equipment. There are different schemes, such as microfinance, warehouse receipting and inventory credits[13]. A loss reduction strategy should be analyzed from a standpoint of finances, which is particularly delicate for small operators in rural areas, and of longevity. This involves taking post-harvest system innovations into consideration with respect to the value chain as a whole, and with this in mind, of identifying the long-term economic benefits and return on investment (Kitinoja *et al.*, 2011; World Bank, 2011).

Reviving proven integrated approaches

Organic waste, crop residues and products unfit for human consumption have always been used for livestock feed, in both southern and northern countries. In return, the cattle provides fertiliser, labour, a nutritious food resource for proteins and micronutrients, an exchange currency and acts as "living capital" as insurance against any future disasters or problems (Faye and Duteurtre, 2009; Faye, 2011). Research re-discovers the complementary functions, which are essential in mixed

13. Warehouse receipt financing is a longstanding method for access to funds practiced in several countries, which involves three parties: the financier, the depositor and the warehouse owner. The depositor, for example a farmer, stores a certain quantity of his product in the warehouse for which the warehouse owner issues a receipt certifying the amount and quality of the product stored. The receipt is equivalent to a guarantee which enables the farmer to apply for a loan from a bank, that he can then use as he wishes. The FAO, the World Bank and the Natural Resources Institute (NRI) promote this scheme in order to develop agricultural sectors and to support dynamic trade (Giovannucci *et al.*, 2000; Coulter, 2010).

crop-livestock systems, between humans, plants, and animals as a source of productivity for food systems, and explores further potential. Such research focuses on improving cereal varieties for example (corn, wheat, sorghum, and millet) with a dual purpose, that of nourishing animals with plant residues without compromising grain yield (Herrero *et al.*, 2010). Other research is exploring integrated systems of the VAC[14] type which integrate aquaculture in order to reuse farming effluents (Mikolasek *et al.*, 2009).

Anaerobic digestion, or methanisation, is another way of using organic waste. Long-known and developed for use by families in South and Southeast Asia and notably in India (from 1954 on by the KVIC[15]), this method has begun to be developed in northern countries.

Following the waste hierarchy defined by community law[16] for waste-related operations, the Netherlands has established a similar, more detailed scale for food waste in particular, the *Moerman* scale (Ministry of Agriculture of the Netherlands, 2010), which guides the use of waste with respect to ethical considerations. Prevention, at the top of this scale, is considered to be optimal since making the most efficient use of foodstuffs. The subsequent levels, from top to bottom, are use in human food and animal feed, industrial uses, fertiliser and energy production and finally incineration and dump disposal.

The basic principle of recovery based systems lies in the idea that there is no ultimate waste: waste from a system becomes raw material for another system, and nutrients are fully recycled. These examples illustrate the importance of replacing the question of food losses and wastage in wider ranging systemic analyses, which address the general issue of production and use of agricultural biomass. Environmental and efficiency concerns about the use of natural resources raise renewed interest for such mixed or integrated farming systems, and for the use of organic waste, in both northern and southern countries. However, when such use becomes the final purpose for agricultural production, it raises the question of competition between uses of agricultural biomass with respect to food demand. It has lately sparked off fierce debates on the ethical and moral dimensions of the various uses of agricultural and food resources.

The concepts of closed loops, circular economy, or industrial ecology, inspired by natural ecosystems in which losses, waste and effluents generated in one system become the inputs for another system (Bourg, 1998), are an important conceptual input for making food systems more sustainable.

Conclusion

Reducing food losses and wastage is not only a moral obligation towards people who do not have the means to eat properly. It would also reduce pressure on ecosystems and on consumer purchasing power and should increase producer income. Faced with the challenge of feeding an estimated 9 billion humans in 2050, this approach merits to be considered a priority as, to date, no new agricultural techniques are likely to rapidly increase production by 30 %. In contrast, cutting by half losses and wastage along the food supply chain appears to be absolutely possible (Foresight, 2011). What is beginning to be perceived as a genuine aberration in both our modern and traditional food systems must become a *leitmotiv* in all strategies leading to more sustainable food systems.

Action levers do exist, but one should keep in mind that it is labour that is costly in northern countries. Whereas the means to reduce losses and wastage exist, it is often not profitable to implement them in the current food system structure or under current marketing and technical conditions. Not labour, but the product is expensive in southern countries. These countries do not have the means (financial and organisational, *etc.*) to invest in wrapping and packaging, in equipment, infrastructure and training.

14. VAC system: from the Vietnamese 'vuon-ao-chuong' which means garden-pond-livestock pen. The most cited VAC system produces garden vegetables, rice, fruit, fish and pork. Other integrated aquaculture systems have been used in different forms in Southeast Asia and India for 1,500 years.

15. Khadi Village Industries Commission.

16. *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF*

Losses and wastage are a complex phenomenon which involves a significant number of strongly interacting stakeholders with different interests. Each one can individually contribute to reduction within his room for manœuvre, but only joint and concerted action will make significant progress to more efficient food use. The use of organic waste related to food losses and wastage fully justifies systemic analysis of production and use of agricultural biomass as a whole.

Finally, before being able to speak of sustainable food systems, real innovations are expected and further multidisciplinary research is necessary (Redlingshöfer and Soyeux, 2011; Foresight, 2011) to enable a real change of paradigm in food systems' organization which puts food back in its rightful place. A 'r-evolution' in attitudes is necessary to get there: considering food losses and wastage as abnormal is a notion that needs to be rediscovered on both an individual and collective basis.

Drawing by Robert Rousso *in le Courrier de l'environnement de l'INRA* nº 25.

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III. Agronomy on the move

A third agricultural frontier to explore?[1]

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The agricultural frontier issue, which seemed to be rather forgotten, is back on the agenda, in a renewed manner, in the framework of recent discussions on world food security: should we clear new land areas (the Amazon, the Congo Basin, *etc.*) to feed humanity in the coming years? The first frontier, well known since the Neolithic era, involving the clearing and farming of "virgin lands", has inexorably been joined by a second frontier over the last century, involving urban development and the development of infrastructures. Here, regulations and the real-estate market dictate the rules, and it is very rare that agricultural land use can stand up to other speculations or decisions of general interest. Finally, new environmental and social challenges encourage us to consider what I would call a third frontier, central to the farming world and based on the actual way of conceiving cropping and livestock breeding and the relations between what is called anthropised environments and natural environments.

Half a century of major transformations in European agriculture

The optimal management of systems considered as stable and predictable has been achieved by eliminating disruptions and by reducing the diversity of the environment, which has led to limiting options and impairing eco-systems' ability to buffer these changes. This has resulted in a simplification of landscapes for crops intended for the market and it has led to:
– the short-term stabilisation of the flow of some resources, without taking ecological thresholds into account much, especially given that these are unstable and difficult to predict
– the masking of feedback from the environment on large spatial scales and over extended time steps
– a new distribution of knowledge, know-how and practices in the management of living organisms… from the country to the laboratories!

Considerable landscape changes

In the second half of the XIXth century, and during the whole of the XXth century, a new economic system imposed itself in the French countryside, in unison with the establishment of higher urban populations and above all with the development of transport networks and means of transport: the creation of national, colonial and international food markets, the development of the agro-industry upstream and downstream, *etc*. The consequences are presented in Hubert, Deverre and Meuret (2010): the market specifies both the areas which are most suitable for each crop, and, right within each locality and farm, the plots of land which have the best economic potential for producing profitable commercial crops, via the use of "modern techniques". The implementation and efficiency of these techniques themselves result from progress made in transportation and the flow of goods (fertilisers, imported livestock feed, fossil energy fuels, *etc.*). Fertilisation is now provided by resources from outside the farm, so farmers no longer have possess or use herds or flocks, which provided most of the fertilisation in the past through the transfer of organic matter

1. Paper for the Cerisy Ethno-technology Seminar (31 dec. 2009). See Gaudin T., Faroult E., 2010, *http://www.ccic-cerisy.asso.fr/ethnotechnologie09.html*

from the pasture land to the cultivated areas, according to the three-field system. This has major consequences on rural landscapes. For example, next to great plains that are favourable or made favourable via drainage and amendment, in hillside areas or mountains, the landscape grid becomes rougher, leading to a dual landscape, made up of cultivated plots confined to valley floors and, on uncultivated slopes, areas which are gradually being planted with trees, either due to plantations, or else due to the simple dynamics of forest growth. The speed of afforestation is often fast (+30 to 40 % of cover in 30 years), homogenizing the landscape on former farmland that is far away and abandoned, on paths, and on unmanaged or neglected slopes. Visible human activities are confined to valley floors that join up with the edge of the forest, thus emphasising the impression of closed landscapes.

The ways and customs, rights and local practices which regulated the relations of individuals and collective bodies to local renewable natural resources have in some ways disappeared in favour of a new dichotomy. On the one hand, the appropriation of productive land benefits either from funds facilitating the acquisition of land and owner occupancy, or else from legislation on "tenant farming" (renting a farm) which favours those who develop land (Deverre, 2005). On the other hand, we are seeing the emergence of public property (for hunting, leisure, *etc.*) on areas which are less and less sought after in terms of property. Land issues have thus been simplified – firstly, priority is given to farmers on cultivable land, supported by individualised management, and secondly, priority is given to various users on the rest, but without any identifiable management or collective regulations, except sometimes those of hunting and naturalist associations for some areas made into reserves.

A profound break in farming knowledge and techniques

In this context, farmers themselves are changing jobs. They are no longer peasant farmers with many activities; they have become specialised producers and "farm operators" whose performance is assessed in terms of energy efficiency and technical-economic criteria. Such a change does not take place spontaneously. It results from considerable national efforts in the adaptation and conception of farming technologies, based on a full array of measures set up under the aegis of the Minister of Agriculture: public agricultural research, technical support services, professional training (initial, continuous and higher). It also benefits from considerable efforts in mutualisation via cooperatives, relations with agro-support and marketing processes in the farming sector, the core of which is still based on the family farm model however.

Within just two generations (the 1960-90 period), modernisation caused what we can call an "epistemic break" with regards knowledge on living organisms (farm animals, plant cultivation and natural resources). On the one hand, practitioners in the field (farmers, breeders, foresters) are in the habit of working on a case by case basis, reproducing and testing solutions suited to their historical, geographical, social and economic conditions. On the other hand, scientists move away from the field and concentrate on doing laboratory work on more and more specialised objects, using efficient techniques and instruments to study biology. Supported by agricultural development services, teams of scientists produce great amounts of knowledge, most of which is "fundamental", *i.e.* designed to be independent of any local context. One glaring example is the genetic improvement of animal breeds (Vissac, 2002; Micoud, 2003) and plant varieties (Bonneuil and Thomas, 2009).

In France, the industrialisation of agriculture has had certain consequences on rural societies. Between 1954 and 1992, agricultural production increased by a factor of two and a half, farm work productivity increased by a factor of ten and the farming population decreased by a factor of four. There were 3 million peasant farmers at the beginning of the 1950s, most of whom carried empirical knowledge learnt from their fathers and peers and now there are 400,000 "farm operators", trained in more than one hundred agricultural colleges and/or closely advised by increasing numbers of specialised technicians. The distribution of knowledge is carried out via a linear model based on the part of scientific and technical knowledge that can be made "generally accessible", *i.e.* the part of this knowledge which is considered communicable and thus carefully standardised. It is also based

on the use of new expertise, related to the appropriation of recommendations supported by "decision support tools".

Seeking new conceptions of farming and the rural world

The agricultural sphere cannot totally isolate itself from the political, economic and social changes taking place in the world around it. In scarcely half a century, we have seen three successive focal points in the farming sector:

(1) Peasant farmers focussed on production and seen as a social group engaged in technical change, within a context of specialised processing of each question by bringing into play disciplines like agronomy, rural sociology and agricultural economics;

(2) Rural areas and ways of inhabiting them are taken into consideration, farmers are seen as a social group undergoing transformations and inter-acting with their neighbours, in a labyrinth of practices and interests, within a context of land-use planning, enlisting the aid of sociology, political science and even of law;

(3) Then environmental issues emerge which are concerned with resources, pollution, the impact of farming activities; farmers become a local social group confronted with global challenges, issues and questions become more complex, processes become interdependent, local and global matters become interdependent, short and long periods interact, and all this is supported by the arrival of ecology, biotechnologies, environmental sciences, *etc.*

In the latter situation, we see the emergence of new spatial divisions (based on naturalistic knowledge) which lead to environmental zoning that differentiates monitoring objectives for the activities (agricultural, forestry, leisure, *etc.*) supported by specifications on the practices of each activity and by the introduction of innovations which protect the environment (agro-forestry models, direct seeding mulch-based cropping, *etc.*). There is talk, for example, of methods (as yet not found) of managing public goods (water quality, biodiversity, landscapes, soils, *etc.*) via the action of private operators, like farmers or land and forest owners (Hervieu, 2002). We are also seeing the emergence of totally new field-based settings (socio-technical networks) made up of mixed groups of players, institutions, regulations, standards, knowledge, projects, actions, *etc.* which generate (i) trans-sectoral experimentation in land management with the consultation of all players (which are growing in numbers) who hardly know each other and who learn how to learn from one another, and (ii) intra-sectoral discussions which could lead to changes in rationality, to the reconstruction of reference models and to the revision of jobs, which may lead to relations being cut off with people and organisations from the usual fields.

Indeed, the agricultural sector already seems to have entered a technological lock in, due to the weight of its previous choices: technological choices (mechanisation, fertilizers, pesticides, genetics, *etc.*), cognitive choices (knowledge and know-how, representations of nature, nuisances, landscapes, *etc.*), political choices (the difficulties encountered when trying to reform the CAP!). As we have observed in other industrial sectors, it is not easy to get out of it, given the prevailing techno-scientific modes of thought and the inertia of the other economic sectors, as well as any political priorities they may have been given. It is much more difficult to fulfil the conditions (in terms of technologies, public policies, forms of social integration, *etc.*) for the emergence of new options to cope with a complexification of issues than to simply ensure the conditions for the continuation of the current technological choices, supported by the usual public policy guidelines, confronted with the social and economic priorities and dynamics, entrenched in social and professional value systems, supported by the technical services system of management and support. This is a well-known trap in technical rationalisation. If, on top of all this, the threat of world famine joins in, and the UN, FAO, NGOs, political-professional lobbies, *etc.* call for an increase in production – interpreted as a productivity increase - in order to reduce famine and poverty, the current productive models are going to have a very bright future!

New specifications for an "ecologically intensive" agriculture/agronomy

Precisely, alternatives to "*business as usual*" have a direct effect on the conception and implementation of production, leading to a reassessment of productive choices which had up until then been considered as "obvious" and bringing out new reference points (diversification, extensification, multifunctionality, ecological intensification, *etc.*), which require new theoretical frameworks, that have to be tested in situ, without ignoring practical know-how if possible. Aiming to create renewable natural resources management based on the cross-fertilisation of agronomic methods and concepts, ecology and social science, by greatly mobilising local knowledge, we can summarise the terms of reference in a few lines:
– Maintain or even increase agricultural yields (9 thousand million inhabitants will have to be fed in 2050);
– Using techniques which are less polluting and less dangerous for farm workers, flora and wildlife (and less expensive);
– Based on better use of eco-system services (pollination, integrated plant protection, nutriment flux, water circulation, *etc.*) and new technologies (IT, genetics, monitoring, *etc.*);
– Mobilising both scientific and local knowledge via cross-learning processes.

Dealing with the Production *vs.* Conservation dilemma

This is the aim of a set of new concepts like Agroecology (Altieri, 1987), Ecoagriculture (Sherr and McNeely, 2007), ecologically intensive production systems (Griffon, 2006), Conservation farming, eco-cultivation, agriculture of High Environmental Value from the French Grenelle Environment Forum, *etc.* For some, these are just new scientific frameworks for 'ecology' oriented agronomy, for others they represent a social view of Development supported by 'value oriented research' and based on a radical criticism of present-day models. Indeed, we may ask ourselves if there are new paradigms behind these concepts: is it simply 'ecological modernisation' applied to agriculture, or the return of 'the systems' approaches, or else an alternative to conventional agriculture relayed by a critical social movement? We even see disciplinary discussions taking place: is agro-ecosystems management a renewed agronomy open to ecological concepts, or else, conversely, ecological engineering, based on ecological paradigms extended to technical action, as an alternative to agronomy?

Behind these different meanings, and there are some truly different ones which we will not develop here, very distinct and even opposing perceptions emerge concerning the matter of the agricultural frontier:

For some, it is mainly a matter of controlling the 'agricultural frontier', *i.e.* containing the cultivation of new areas to the detriment of forests and protected wilderness areas, via zoning, the creation of new territorial governance institutions, economies of scale, the payment of eco-system services, trans-sectoral cognitive exchanges, *etc.* It is a matter of developing agriculture where it actually is, in order to ensure – as far as possible – food for the inhabitants of the planet (and in forty years, there will be about 9 thousand million inhabitants), while at the same time ensuring that the main ecological functions are protected at least in non-cultivated areas ("avoided deforestation", "REDD", "carbon" compensation, *etc.*) because we cannot be sure that they will be protected in the areas devoted to production.

For others, it is a matter of transforming agriculture and not only reconstructing it, by working at territorial and also sectoral level, in order to:
– Create landscape mosaics, based on a dynamic connectivity between environments (ecological corridors, ecotones, *etc.*) and on the heterogeneity of these different types of ecosystems;
– Generate economies of diversity and scope (farmers, products and outputs, knowledge, genetic material) and no longer economies of scale;
– Take into account bundles of rights regarding the use of resources (access, use, transmission, devolution, land allocation, genetic material, *etc.*) and not only in terms of land and resources appropriation.

According to this view, we should go beyond the usual frontiers between urban areas, the countryside and natural areas, by developing urban and peri-urban agriculture, agroforestry, agro-ecology, integrated management of wetlands not only via drainage, *etc.* In short, we should place our bets on the complementarities between differentiated areas and production systems, without marginalising areas that are not very productive or the people who live there! This means we should reconsider the current modes of separation between areas of production and protected areas (sanctuarized areas), via the creation of eco-system mosaics that provide a variety of functions and services, some of which are called agro-eco-systems, in a holistic view connecting societies to their environment through the notion of a socio-eco-system.

Stratification *vs.* Integration: designing a new agricultural frontier!

Here are two opposing views of spatial planning, presented in a rather caricatural way:

– Stratification of areas, and consequently of rural communities, may lead to increased inequalities with regards land allocation, indigenous people and farmers' rights, food security, *etc.* In the name of environmental protection, it can even bring with it a form of eco-imperialism of western values which contrast with local values on species and habitats, and which is likely to lead to conflicts in terms of 'environmental justice';

– As for integration, it aims to encourage diversity at different levels via a whole set of production systems (different sizes, types of households, products, availability for work, *etc.*), promoting a diversity of environments and leading to better productivity of the whole (promoting heterogeneity and complementarities).

However, with this integration a new agrarian frontier needs to be thought up, because it associates a diversity of functions and services in the same area (Hubert and Billaud, 2008; Hubert and Caron, 2009). Thus, for example, the issue of urban development generates increased competition between urban space and agricultural space for real-estate and natural resources (drinking water, fuel wood, *etc.*), not to mention the social tension that could result from this. Therefore, it is probably time to think differently about what a real peri-urban and urban agriculture would be like, how it could avoid being a rival, beaten before it had began, to residential or industrial extension. To the contrary, it would help create a town landscape network via areas devoted to production; however it would raise questions on the rehabilitation and conservation of soils polluted by waste and previous facilities, or even simply subjected to the effects and consequences of various urban activities. It would also call into question the organisational dimensions involved in the marketing and distribution of food, by the creation of short channels, most of which elude the usual food marketing operators, either by the development of nearby 'traditional' markets, thus connecting urban consumers and local producers, or even, as has been seen in Europe, in some towns in North America and in emerging countries like Brazil, new forms of direct agreements between groups of consumers and producers based on specifications and guaranteed prices set in advance determining a commitment to supply the households concerned throughout the whole year of production (Lamine, 2008).

Those who defend the inviolability of the first frontier do so nowadays in the name of environmental challenges. Indeed, the issues of biodiversity, soil protection, the preservation of water resources and their quality, efforts to slow down climate change by carbon fixation justify that we stop destroying the planet's great forests (the Amazon, Congo Basin, *etc.*) and draining wetlands for their "agricultural development", except when there is compensation like in the United States. Therefore, we need to intensify, without touching the frontier, and if possible develop "cleaner" agriculture on the areas dedicated to it, just like the ecoagriculture proposed by Jeff McNeely, Chief Scientist at the UICN. From this point of view, we can even ask ourselves whether the eco-services, much praised today, are actually intended to ensure compensation and guarantees with regards some major aspects of planetary equilibrium, in the event of various technical blunders (biological contaminants and abiotics), given the technological challenge of feeding 9 thousand million inhabitants in 2050. Today, it is not a matter of presenting this frontier as a land reserve, but even so, the question will obviously be raised for the taiga, when the disappearance of the permafrost arouses the desire to

"develop" these soils containing an abundance of organic material stored since the last glaciations and which are just begging to release CO_2: it will take a long time before they are exhausted!

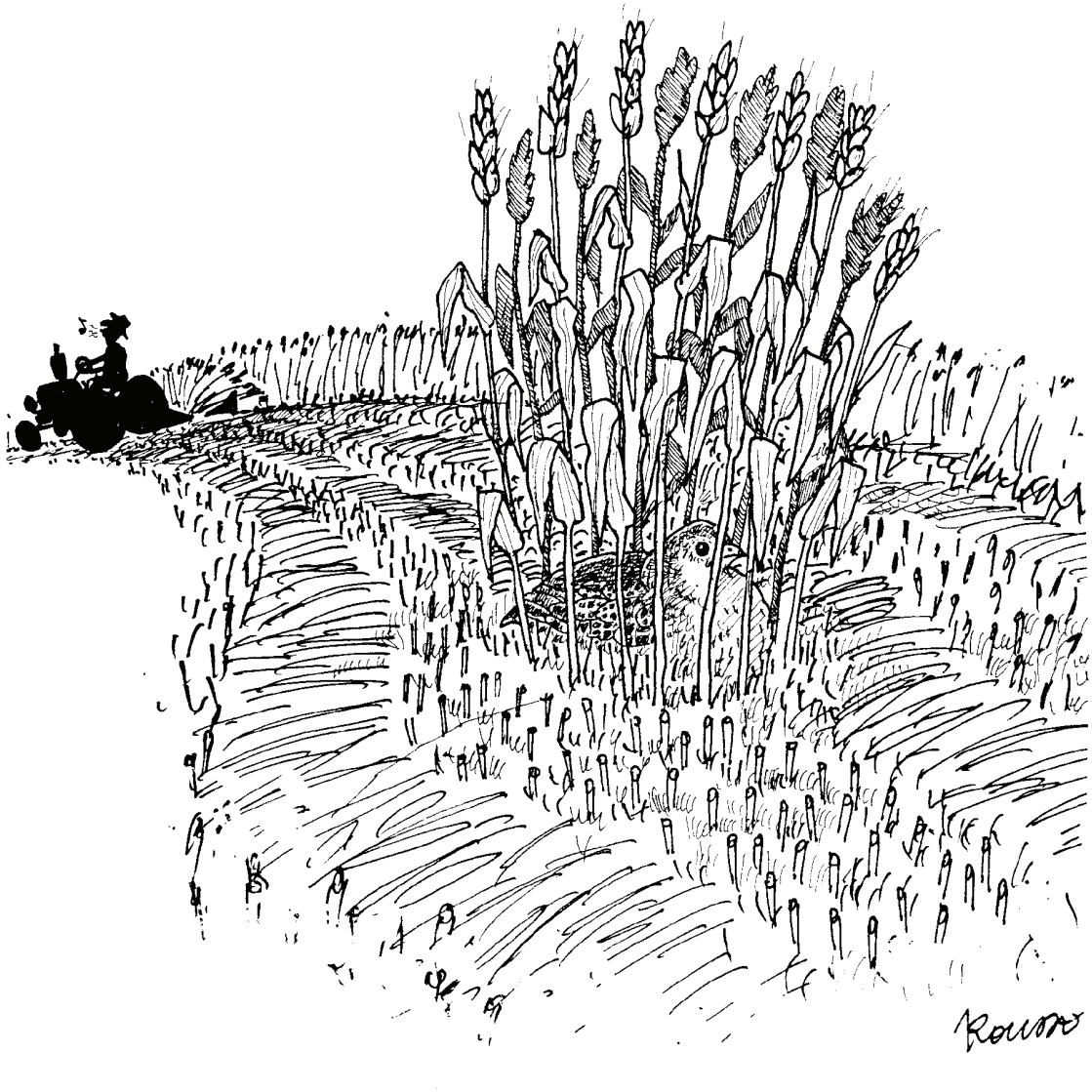
Maybe it's time we posed the question differently and prepared for a third frontier: this would mean re-examining the actual concepts and practices of agriculture and re-thinking the world's current tri-partition into towns where populations concentrate, rural areas devoted to agriculture and forestry, and wilderness areas serving as guarantors for Nature's offer and preservation the planet's important balances. Indeed, we should create a diversity and complementarity of forms of farming based on knowledge and practices, technical models and marketing circuits that will differ according to crops, geographical situations, forms of public action, cultural values, and individual or collective commitments. These forms of farming could network urban areas, penetrate forest boundaries, introduce completely new ecological mosaics and invent ways to produce which are inspired by ecology rather than chemistry, based on Altieri's agroecological models. They would restore the diversity and variability of animal and plant genetic material and be able to adapt to slopes, hollows, edges of woods, stories and wooded stratums, while respecting them and at the same time producing crops... and reproducing themselves. However, it is no longer simply a matter of respecting the environment or, what is worse, reconciling agriculture with the environment, but of turning the environment into a production of agriculture, among its other productions.

To ensure this, we need to move away from a compartmentalised world where space, activities, production, knowledge and research obey the same law of specialisation. This leads to a reversal of point of view on the multifunctionality of agriculture, as one of the essential points, in the IAASTD recommendations (2008) and in the 2008 World Bank report devoted to agricultural issues, and more information on this should be given than has been done up until now. One of the first tasks to be carried out to make it meaningful would be to produce performance criteria to evaluate the quality of the way in which these different functions are carried out, if only to be able to make them policy and manage them, and even to remunerate them. We would then see that within this scheme, the different types of agriculture mentioned in the previous paragraph complement each other rather than complying with a single model. However, we need to define performance criteria – and a related measurement system – which take these complementarities and functionalities into account on organisational levels that encompass individual farms, while all current indicators are only concerned with aspects of one farm – and sometimes only with the plot! – and mainly focus on technical-economic criteria.

Finally, in both cases, but even more so in the integration model, we can ask ourselves whether new technological choices (thus social, economic, spatial planning, *etc.* choices) are really capable of emerging? It may prove difficult to get away from the current choices which are very integrated, not only in the panel of technical solutions mentioned above (mechanisation, fertilisers, pesticides, genetics, *etc.*) but also in the cognitive systems (knowledge and know-how, representations of nature, nuisances, landscapes, *etc.*) and in the values (which is a good thing!) of the main players involved, from the farming profession but also the departments and administrations around them, the current techno-scientific modes of thought and the priorities given to the other economic sectors. Will we be capable of going beyond the lock in situation described above?

A different paradigm and a real conceptual break

It is a matter of being able to move away from a framework in which an agro-ecosystem is seen as the sum of the relations between consumption and production in an environment considered as stable (or foreseeable) to the management (stewardship) of eco-system functionalities in order to facilitate "eco-services" and the acquisition of knowledge and skills like the ability to adapt to changes (climate, politics, values, standards, *etc.*) by drawing on new concepts: dynamics, thresholds, resilience, viability kernel, learning process and collective action, *etc.* Such an approach is based on the co-evolution and interaction of the system/environment in a situation of uncertainty!



Drawing by Robert Rousso *in le Courrier de l'environnement de l'INRA* nº 41.

We can draw on the proposals made by Paul Thompson (1997) who offers two approaches to the management of renewable natural resources in a sustainable development perspective.

Resource sufficiency

A classic approach in terms of "Resource sufficiency", which is based on a utilitarian view of nature and on the concept that resources are like a given capital (a stock), which can be considered as abundant, renewable or critical and which offers the following solutions to ensure the sustainability of these decreasing resources:
– Reduce their rate of consumption;
– Or increase their use efficiency;
– Or finally, replace them with other resources via a change in technology.

According to this view, the state of an agro-ecosystem consists in the sum of resource creation minus resource consumption, in an environment considered as stable enough to ignore its variations. They lead to policies being based on the improvement of their efficiency, in a universal perspective, all other factors being equal.

Functional integrity

An innovative approach that he calls "Functional integrity", based on a process of co-evolution, with resources emerging from the interaction within a social eco-system, the critical points (technical or social) of which need to be identified, *i.e.* those which jeopardise its sustainability, and in this case those which jeopardise its own capacity for transformation. All the activities and forms of social organisation that interact need to be studied. This approach leads to policies adapted to local situations, which focus on the securement of these critical points and which must be contextualised and adapted. The application of these policies must be regularly monitored and assessed, avoiding prescriptive and centralised measures. Sustainability must be seen as a property that emerges from the interaction between players and their environment and not as an intrinsic and technical quality of the eco-system.

These days, many farming practices (forestry, halieutics, *etc.*) are unsustainable, and even counter-productive, because the players involved are only concerned with how resources can be produced and farmed and they do not consider resources as dynamic elements which transform themselves through their inter-connection with complex eco-systems. It is time we produced conceptual frameworks (theories, methodologies, evaluations, *etc.*) to allow us to devise other practices which respect both the environment and the societies that work them!

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Reinventing agricultural systems: what sort of agronomy for sustainable development?[1]

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Between the middle and end of the XXth century, western European agriculture underwent profound changes, as a result of proactive agricultural policies aimed at ensuring food self-sufficiency for the European Union and releasing manpower for industry. These policies were a total success, leading simultaneously to a considerable reduction in the number of farms and to an unprecedented increase in productivity per hectare. Intensive systems which use a lot of chemical inputs (fertilisers, pesticides, veterinarian products) and which are largely mechanised now dominate Western European agriculture. However, the sustainability of these intensive systems is now being called into question: they are energy-consuming, bad for biodiversity, they pollute water with nitrates, phosphates and pesticides and they produce greenhouse gases, *etc*. As the spectre of food shortages has been removed, agriculture has been incriminated by urbanites and ordered to become «ecological». For the past 20 years, the world of farming has paid attention to this demand and attempted to address it, controlling the most serious nuisances (reducing nitrite pollution, using pesticide treatments on a case by case basis, *etc*.), without giving up their efforts to improve productivity. However, the question now is: would small adjustments to the intensive system be efficient in controlling the nuisances that nobody denies exist any more? If so, what adjustments are necessary and possible? If not, how can we re-invent production systems which meet the objectives of sustainable development, *i.e.* ensuring food security for rural and urban populations and a regular and adequate revenue for farmers; resource-efficient production systems which encourage the expression of eco-service systems and territorial social cohesion (FNH, 2009)? In the first part of this chapter, we shall analyse the economic, social and agronomic thinking behind current systems, to identify the leeway that exists in terms of reducing ecological nuisance. In the second part, we shall give some suggestions and guidelines for Agricultural Research & Development and public action aimed at encouraging the necessary changes.

Current agricultural systems: economic, social and agronomic thinking; players' interaction and "lock-in" situations

The forms of agriculture adopted in Europe, which are heavily dependent on soils and the climate, vary greatly from one place to another. However, the main processes which have marked the development of production systems are the same everywhere: (i) a specialisation of farms and territories, and (ii) increased dependence on external input. Pesticides have become vital elements, especially

1. Extract from the book *Vers une société sobre et désirable*, under the direction of Dominique Bourg and Alain Papaux. "Sustainable Development and Institutional Innovation", PUF Editions Paris, 2010. Permission granted © PUF, Paris, 2010.

in plant production systems. These processes will be illustrated through the Paris Basin grain production systems in France.

The specialisation of territories and production systems

Present-day landscapes in the North of France were formed by a specialisation of territories and production systems. The West (Brittany, in particular) has become a region devoted to intensive livestock production for example, while the Paris Basin has become devoted to field crops with very little livestock production. Polyculture and livestock production, which used to be present in most regions, have become less and less widespread. Figure 1, taken from Schott *et al* (2009), illustrates the consequences of these changes on land-use.

The maps represent the Seine river drainage basin (in the north-west - the Normandy coast, in the south - the Morvan), *i.e.* approximately 100,000 km^2. The map shows that the regression in the production of ruminants in the centre of the Seine basin (Beauce, Perche, Brie, Picardie, *etc*.) has led to a marked regression in the surface area of natural grassland. In 2000, these only occupied significant areas in the outer regions of the Seine basin, such Normandy in the west, the Thiérache in the north or Burgundy in the east. The regression of livestock production and grasslands is accompanied by increased areas of field crops, the most important being wheat, which now occupies over 50 % of the agricultural area (AA) in use in some regions. This specialisation in itself raises environmental issues: Loss of biodiversity when grasslands are replaced with annual crops; reduced wetland areas when land is drained for cultivation; reduced habitat diversity which has a negative impact on biodiversity; low recycling of minerals (N, P, K, *etc*.) on farms, which results in a wastage of non-renewable resources.

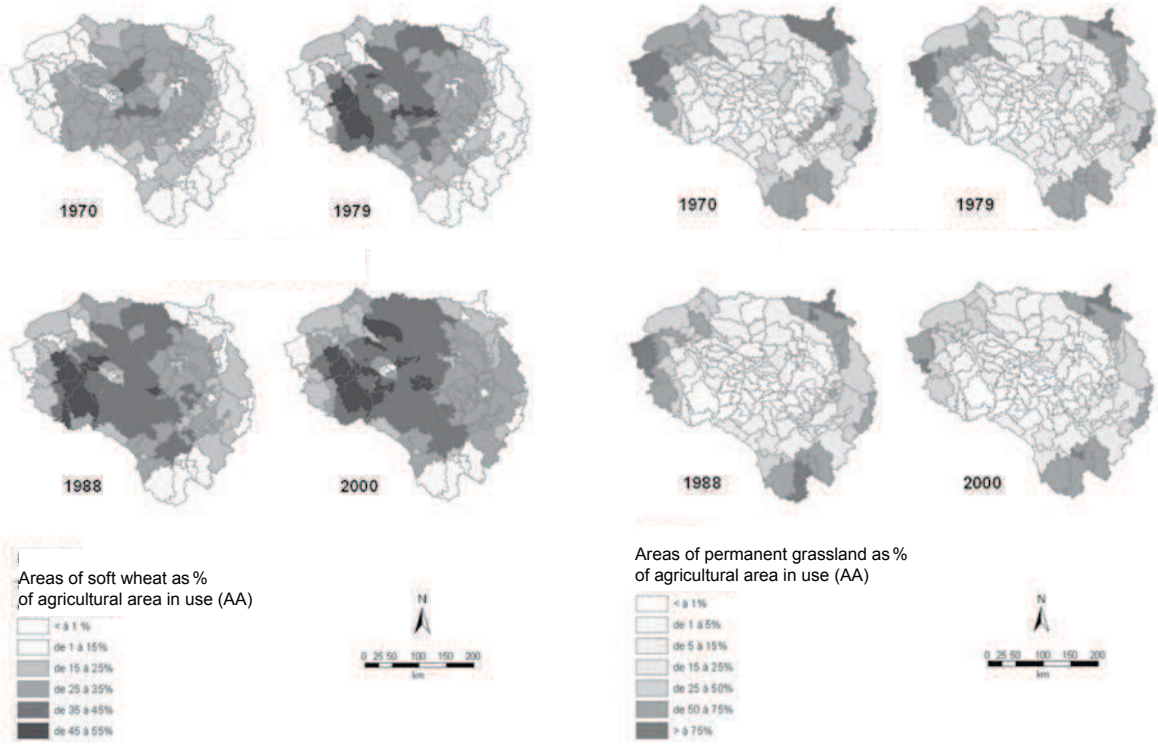


Figure 1. Specialisation of production basins and farms: Changing surface areas of winter wheat (maps on the left) and natural grassland (maps on right) in the Seine basin between 1970 and 2000. ***Source: Agreste and INRA Mirecourt.***

This territorial specialisation is structured by agro-industrial installations which ensure outlets for the products. With increasing levels of expertise required in production processes, specialised farmers and their advisors only source their skills in their fields of specialisation. Therefore, it becomes even more difficult for farmers to re-diversify, because not only do they have to find outlets that no longer exist locally, but they also have to acquire knowledge and technical references on new products without any local support.

The case of alfalfa, illustrated in figure 2, symbolises this regional specialisation, conceived when energy resources were thought to be unlimited. In the 1970s, alfalfa was present all over the Seine basin, and usually consumed by livestock on the farms where it was grown. Its decline followed that of the polyculture / livestock production system, and between 1980 and 2000, alfalfa became concentrated in the Champagne Crayeuse region (dark area on the map for 2000), in an area that favoured high levels of production (soil with high-lime and high moisture reserves), to supply the "dehydration" sector: alfalfa is dehydrated using fossil energy, so it can be easily conserved, transported and incorporated into the livestock feed sold to the livestock producers in regions specialised in livestock production. In the 2000s, there was a decline in this energy-consuming channel, due to increased energy prices, less support from Europe and competition from soybean cake from the American continent.

A reduction in the number of species cultivated

Generally speaking, alongside this regional specialisation in the field crop areas, there was a reduction in the number of species cultivated, and shortened crop rotations. Thus, in comparison with the 1980s, in the Seine basin, the surface areas of wheat and rapeseed greatly increased, while the surface areas of protein pea, sunflower, and corn decreased; monocultures of wheat, and short rotations such as rapeseed / wheat / wheat or rapeseed / wheat / barley became more frequent (Schott *et al*, *op.cit.*). The whole channel is involved in this crop system simplification: The recent regression in the surface areas of protein peas (divided by a factor of 7 in 15 years in France between 1994 and 2009) is an example of this. The development of protein peas in the 1980s was due to the determined support of public authorities (high price guaranteed, support for varietal selection), related to a desire to reduce the European Union's dependence on imported sources of proteins (soybean cake). Surface areas started to decline after public authorities reduced their support, and when a new disease called Aphanomyces developed (in this crop's heyday, in the 1980s and the early 1990s, some farmers cultivated peas on the same plots of

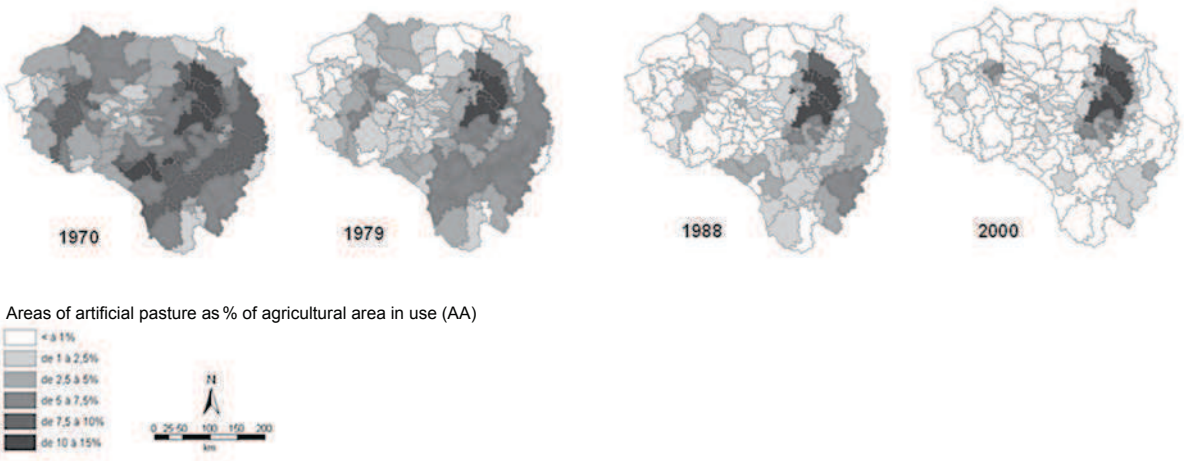


Figure 2. Alfalfa, a symbolic case of resource-intensive farming: Changing surface areas of Alfalfa in the Seine basin between 1970 and 2000. ***Source: Agreste and INRA Mirecourt.***

land rather too frequently and this helped the disease spread). The declining surface areas undermined the credibility of pea production among livestock feed manufacturers, who no longer had a guaranteed supply. Market prices suffered and this led to an even faster decline in surface areas. Soybean cake once again became the essential source of proteins in livestock feed. Private seed producers called the future of peas into question and invested less in the selection of new varieties. Therefore, the productivity differential between protein peas and wheat or rapeseed, which continued to benefit from selection efforts, was not reduced, which is essential if protein peas are to become economically viable again. It was the overlapping strategies of the different players involved in the channel which led to the decline of peas, and which will greatly complicate the revival that public authorities hope for.

The key role of pesticides

Shortened crop rotations increase the problems of telluric parasitism and weed populations. When surface areas are heavily devoted to certain species, the risk of epidemics and airborne parasites increases. Therefore, without pesticides, all this specialisation would be impossible. In fact, pesticides have become the keystone to current intensive cultivation systems, and they structure not only the rotations but also the sowing dates and choice of varieties. Let us take the example of wheat crops (Meynard and Girardin, 1992). To maximise yields, it is sown early and densely and nitrogen is regularly applied, and the most productive varieties are chosen (which are not usually the most disease-resistant ones). All these choices encourage productivity but also parasitic insects, fungal diseases and weeds. To deal with these high risks, a thick cover of phytosanitary crop treatments is necessary. To ensure that work can be carried out fast and easily, farmers have bought powerful, wide equipment and tried to regroup and enlarge their plots of land. Thus, field crop landscapes are dominated by intensive systems practised on large, genetically homogenous and pesticide-intensive plots.

This key role played by pesticides in the landscapes of field crop regions is reinforced by the advisory system and selection priorities. In the field of pesticides, innovation is very active, and farmers depend upon an outside advisory system for their use (Butault *et al*, 2010):

– Technical advice is mainly attached to the sale of inputs. It gives priority to simple solutions (1 problem, 1 solution) rather than preventive agronomic methods which are more complicated to implement and not as immediately effective.

– Varietal resistances are usually considered as supplementary to pesticides and not as prime means of fighting pests. The market for multi-resistant varieties remains limited and so this does not incite players to prioritise this selection market.

– Given the secondary role of varietal resistances, there is no coordination of varietal choice with a view to resistance management. The circumvention of resistances tends to undermine the credibility of this solution.

Locked-in agricultural systems

Therefore, agricultural production systems appear to be totally coherent with the organisation of upstream and downstream channels, and with the communication systems. Each player's strategy reinforces the others' strategy. It is in nobody's interest to change strategies as long as the others do not do so. This is a typical case of lock-in, a term coined by researchers in sociology and innovation economy (see for example the effects of lock-in and the use of pesticides in different countries, Cowan and Gunby, 1996 or Wilson and Tisdell, 2001). This very coherent social-technical system results from the remarkable way in which the agricultural world responded to the injunction to increase the production of cereals, and to increase international competitiveness. Clearly, this coherence is hard hit when required to integrate new injunctions related to the environment: we cannot change production methods by simply saying "just do it" or by simply distributing information: simultaneous action needs to be taken at several points of the system in order to unlock it.

Getting agricultural systems to change: What kind of agronomy is needed to ensure sustainable development?

Although we can agree upon the need to make great changes to agricultural systems and align them with sustainable development, it would be presumptuous to attempt to define what they should be like in this paper. The systems to invent will result from a great deal of interaction between international agreements, public policies, and players involved in economics and agro-ecosystems: they cannot be predicted. Therefore, we have decided to address the question of levers rather than the results of their transformation, keeping the example of field crop systems in the Paris Basin as the guiding theme. The previous analysis suggests that significant changes to agricultural systems can only be achieved by implementing coordinated action aimed at softening the strategies of the main players in order to "unlock" the social-technical systems.

Focussing efforts on the system's keystone: pesticide reduction

Technical solutions that would greatly reduce the use of pesticides now exist (Meynard, 2010), *e.g.* disease-resistant varieties, low input wheat management techniques, the diversification of crop sequences, the association of varieties and species, mechanical weeding, landscaping (grass strips, hedges, *etc*.) which encourage auxiliaries, *etc*. The problems is that none of these alternative solutions taken individually is as efficient as pesticides: "integrated plant protection" is based on a case-by-case combination of techniques which produce partial effects. It can only develop if more field-based action is taken, helping farmers get to grips with new techniques, adapting them to their situation, combining them and encouraging learning.

The example of a farm in Picardie studied by Mischler *et al* (2009) can be used to illustrate this. In 2002, an agronomic and environmental diagnosis was carried out by the farmer and an advisor: A major weakness was highlighted: an intensive use of pesticides (pesticide treatment frequency index (IFT) of 8), on poorly diversified crop rotations. The technician and farmer then examined the possible solutions together: what new crops could be introduced? What markets were there? Were they compatible with the farmer's equipment? Were they compatible with his organisation of work? What management methods and what variety should be adopted for each crop to limit pest risks? Was it possible to weed mechanically? Was it possible to associate species or varieties? The farmer chose some innovations from the "innovation library" offered by the advisor, taking his specific constraints into account; he tried the innovations on a plot of land, adapted them, combined them and then extended them to his whole farm. Six years later, he had diversified his crop rotations, changed his varieties and cultivation methods and reduced his mean IFT to 3. The working time was slightly longer but the revenue had not been effected. The diagnosis can be repeated, thus initiating a new improvement loop.

What lessons can be drawn from this experience? Three types of tools were necessary:
– a battery of diagnostic indicators, which could be easily estimated and appropriated by the farmers.
– an innovation library, with information on the advantages and disadvantages of each innovation: working time, equipment and skills necessary, impact expected on the environment and production, systemic effects on other practices, *etc*.
– finally, discussion groups for farmers undertaking similar initiatives. These changes, which call into question the practices, knowledge, social representations and organisation, are extremely unsettling. The groups play an essential role in the innovative system learning process; they offer a source of ideas, multiply the number of experiments and offer moral support to help farmers cope with the risk-taking (Lamine *et al*, 2009).

Helping new channels emerge in order to re-diversify the species cultivated

It is of course possible to promote crop diversification via regulations or the conditionality of farm assistance. However, this diversification can only continue over the long term if the action taken by public authorities is sustained via market mechanisms. It is a matter of helping new channels emerge, become consolidated, and become credible because the "locked-in" social-technical system

leaves them very little opportunity to do so nowadays. This would involve coordinated action in (i) the innovation of processing technologies, (ii) the selection of dedicated species, and (iii) agronomic R&D. A considerable amount of work needs to be done in the selection of orphan species, and no doubt government research will have a role to play in this.

Generally, it would be preferable if public policies as a whole integrated this need for crop re-diversification: for example, the support given to the development of agro-fuel has up until now mainly benefitted species which already occupy very large surface areas (wheat and rapeseed in particular) and has helped accentuate shortened crop rotations. Developing lignocellulose-based energy production (second-generation agro-fuels) could help promote the diversification of species, like alfalfa or sorghum, but could also lead to the concentration of monocultures of dedicated species around processing facilities if this eventuality is not anticipated. In the medium and long-term, we should consider the possibility of re-introducing livestock production into the regions from which it has disappeared; this would contribute to crop diversification and also to local recycling of fertilising elements.

Supporting innovation in agro-ecology

As many authors now point out (see Griffon 2006 or Wesel, 2009 for example), sustainable development calls for the creation of production systems (at the interface of ecology and agronomy) that are ecologically intensive and that mobilise eco-service system regulations for production processes. However, as agro-ecological innovations are usually non-commercial, their development (as we have seen in the past) depends mainly on government research and on development agencies which provide non-commercial advice. Yet, both in research and agricultural development, systemic approaches in agronomy have just emerged from 20 years of purgatory, during which skills were only partially renewed. Biotechnological engineering has eclipsed agro-ecological engineering (Vanloqueren and Baret, 2009).

The creation of agro-ecological systems should mobilise and coordinate research and development agencies, the players involved in the channels and territories, and the farmers. It should simultaneously concern work done at plot level, at farm level and at landscape level and should be based on in-depth methodological renewal which particularly mobilises model building and participatory research, in addition to traditional experimentation, much appreciated by agronomists. A special effort should be put into genetic innovations adapted to agro-ecological systems: hardy varieties, open-pollinated varieties, species diversification, *etc*. Selection companies should only become involved in this process if they anticipate seed markets. This commitment requires a long-term visibility of government policies and of their consequences on seed markets.

Reorganising farm advisory systems and encouraging learning

Technical advice is now very analytical: in technical farming journals, the advantage of each technical choice is emphasised much more than the way in which they can be combined (Butault *et al*, 2010). This is not illogical: the ways in which they can be combined must be dealt with locally, depending on the characteristics of the environment, the farmer's production tools and the specific markets for the products. Sociological research indicates that one of the keys to a robust transition to integrated production is support for farmers in their learning process (Lamine *et al*, 2009). Therefore, technical advice on the use of inputs must be replaced by support on the transformation of production systems, bringing together scientific knowledge and local knowledge. To achieve this, three complementary actions can be suggested:
– develop the role played by self-assessment in practices and systemic approaches in the training of future farmers and agricultural advisors;
– promote the development of tools to assess farming practices and understand their impact on eco-services, and thus integrate these impacts into learning processes;
– in the environmental regulations, replace the obligation of means with the obligation of results. For an agronomist, the obligation of means, which usually takes the form of codes of good farming

practices (BPA), is indeed an aberration. There are several reasons for this: (i) the codes of good farming practices (BPA) aim to standardise practices, sometimes putting great pressure on farmers' ability to adapt to the diversity of soils, climates and farming situations; (ii) the basic farming techniques are codified but environmental impacts are often related to several techniques; (iii) they are considered as constraints: thus devalorising environmental protection in the eyes of the farmers. On the contrary, the obligation of results, based on an ecological result indicator which is accessible to farmers, allows them to make a lucid diagnosis of their situation and encourages the implementation of virtuous improvement loops, like those described above.

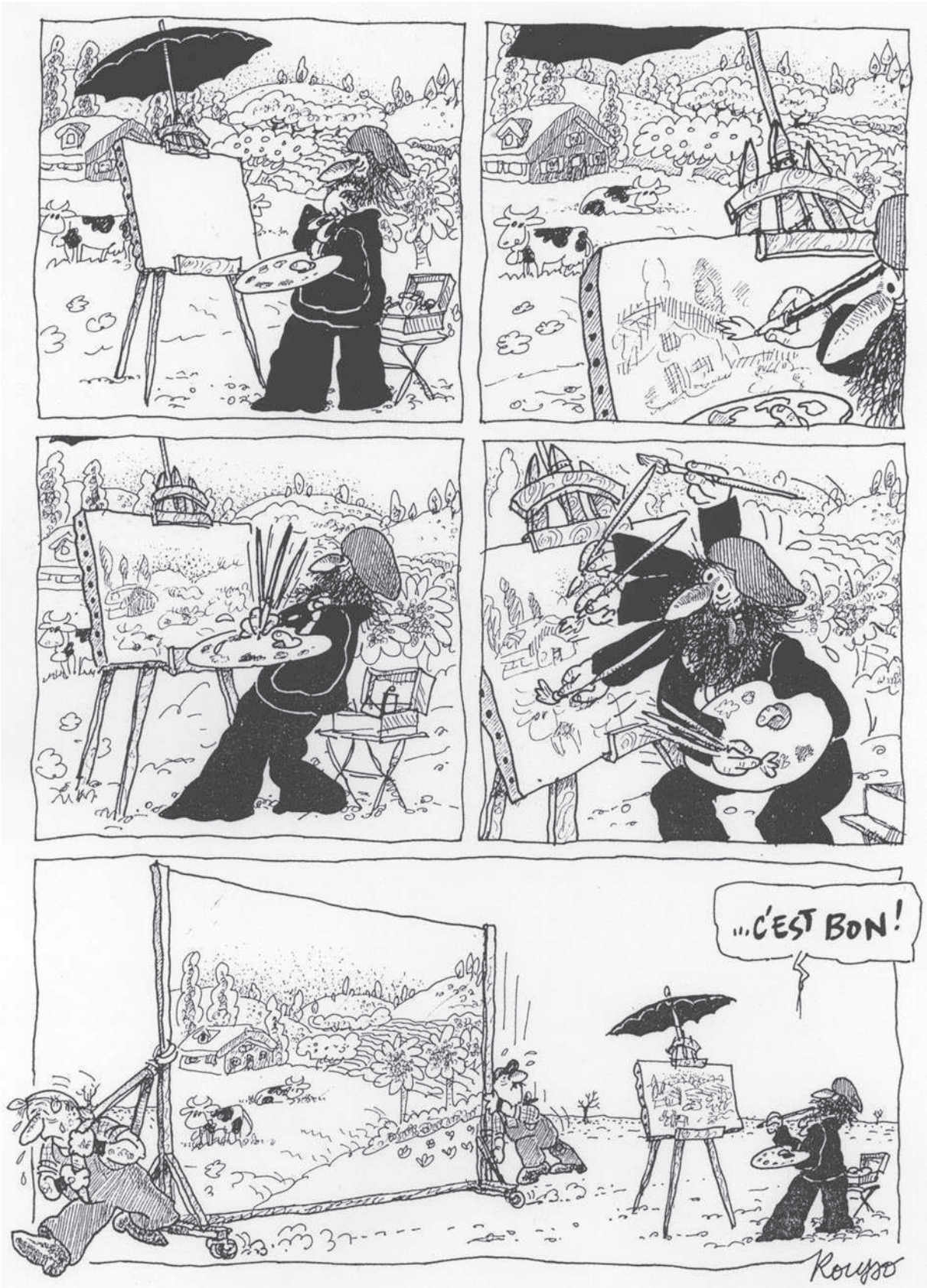
Encouraging collective dynamics and territorial coordination

Setting up agro-ecological systems, particularly methods of combating bio-aggressors that are alternatives to pesticides, requires the implementation of coordinated action at territorial level (*e.g.* diversity of varieties to limit the risk of circumventing genetic resistance to pathogens, territorial prophylactic measures, landscapes that encourage the multiplication of auxiliaries that protect crops, *etc*.), yet technical advice is mainly aimed at individual farmers and does little to promote collective action (Butault *et al*, 2010). Literature on collective organisation (ComMod, 2005, Pahl-wostl, 2005) shows that several conditions must be fulfilled if such operations are to succeed: (i) an agreement on the need to act and on the outlines of the collective organisation in question; (ii) a shared view of the processes to manage, which may take the form of a model built through research or expert judgement; (iii) the setting up of a consensus process, which may be based on the construction of action scenarios, role plays, *etc*. Public authorities definitely have a major role to play to legitimise a shift in position of farmers and advisory bodies in relation to territorial coordination: financial incentives to take collective action, setting up pilot experiments, coordinated action certifications for some territorial players, *etc*. In relation to the last point, it seems that in field crop systems, companies that combine the collection and sale of inputs, such as agricultural cooperatives in France, could play a major role in the organisation of territorial coordination of practices, particularly to reduce the use of phytosanitary products: indeed, they usually operate on clearly defined territories with surface areas of several thousand km^2, and they interact with farmers both upstream and downstream: input sales, advice, collection, advice, contracts, *etc*. They sell seeds to farmers and could promote disease-resistant varieties and mixtures of varieties or species. A lot of attention is paid to the advice they give, and, through their collection function, they could encourage diversification.

Conclusion

In the complex and generally "locked-in" situation that has just been described, it is clear that all the players concerned, and first of all the public authorities, must think and act in a systemic manner. Simplifications like "one problem, one solution" or "one public policy objective, one instrument" are appealing but they are notions of the past. Public authorities have a major role to play in mobilising all the players affected by the changes necessary in agriculture. Different instruments can be used: classic economic instruments (taxation, quotas, bans, rights markets, subsidies, *etc*.), but also by supporting innovation, learning processes, collective action, *etc*.

If public authorities are to act upon the extremely static economic and social dynamics of the farming world, they will have to prepare changes for 2030 very soon, via initiatives involving farmer training programmes, support for agro-ecological innovation, the reorganisation of advisory systems, *etc*. Moreover, a clear message must be sent to the players, so that they start making the necessary changes but this will require constancy in public policies and transparency in changing regulations. We are tempted to think that one of the obstacles to the development of sustainable farming today is the fact that the public policies themselves are not sustainable enough.



Drawing by Robert Rousso *in le Courrier de l'environnement de l'INRA* nº 20.

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Demographic growth, obstacle or opportunity for sustainable agricultural intensification in Sub-Saharan Africa? The agrarian transition and the resilience of rural societies[1]

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The complexity of agricultural situations in today's Africa leaves no room for simplistic judgements. This is an area where statistical and economic considerations cannot be dissociated from more comprehensive approaches involving detailed observation and intuition.

Philippe Couty *(L'agriculture africaine en réserve)*

Demographic growth, a controversial influence…

Assessing agricultural and rural development in Sub-Saharan Africa after forty years of independence, the results hardly look positive. The gap in development between this region and the rest of the world seems to grow deeper every year, suggesting the Afro-pessimists are right. The reasons for this gap are many. One that is frequently quoted is the burden of high demographic growth. As far back as 1962, René Dumont considered in *L'Afrique noire est mal partie* ("False Start in Africa") that limiting this high level of demographic growth was an essential condition for the development of African agriculture. And yet analyses of this factor's effect on agricultural development are far from unanimous.

Stereotyping slightly the positions taken on this issue of demographic growth, we can say that they reflect an opposition between two hypotheses about the effect of demographic growth on the evolution of agricultural production.

The first and more widespread position, the one expressed, often unconsciously, in the media, politicians' speeches and even scientific journals, clearly refers to the theory of Malthus. According to this theory, set out in his *Essay on the Principle of Population* (1798), a rise in the rural population leads to increased pressure on resources, and the land in particular, which in turn leads to a drop in its fertility, diminishing crop yields and thus reducing the agricultural production available, ultimately leading to famine which, in a way, restores the balance between the population and the productive capacity of the land in question.

In the modern version of this theory adopted by neo-Malthusians, migration replaces famine when the imbalance between a habitat's productive capacity and the needs of the populations living there grows too high.

1. This text was first published as paper in *Le Courrier de l'environnement de l'INRA* n° 52, septembre 2004, 101-106.

This point of view is opposed by the thesis of Ester Boserup. In her book *The Conditions of Agricultural Growth* (1965), she adopts a position that is the exact opposite of Malthus' theory, considering that in non-industrialised countries (as we shall see later, this distinction is important, though often overlooked by her detractors) an increase in rural populations is a favourable factor for agricultural intensification, and that under these conditions it is an illusion to expect agricultural production to intensify if population density is low.

Close observation of agrarian situations in Sub-Saharan Africa shows that some do indeed experience Malthusian development while others are undoubtedly closer to a Boserupian logic.

For example, the evolving condition of the natural resources in Yatenga (Burkina Faso) under the effect of increased pressure on the land as described by Marchal (1983) and the situation in the Serer region of Senegal reported by Lericollais (1970) confirm fairly clearly a Malthusian-type dynamic, and there are many other examples on the African continent that demonstrate that increasing pressure on land results in overexploitation of the habitat and degradation of the environment, threatening agricultural sustainability.

But alongside these situations we can also identify regions where high population density does not result in this environmental degradation; on the contrary, it leads to intensified agriculture and the sustainable management of the habitat's productive capacity. These regions include Bamileke in south-western Cameroon, where certain areas with population densities approaching 1,000 people per km^2 manage to produce surpluses that feed the cities of Douala and Yaoundé. Another striking example of Boserupian development is the Machakos district in Kenya, where population growth over several decades has been accompanied by unquestionable agricultural intensification and improved management of the habitat's resources, as reported by Mary Tiffen, Michael Mortimore and F Gichuki in their explicitly-titled book *More People, Less Erosion*.

This underlines a contradiction which it will be very important to resolve if we wish to evaluate the impact of demographic growth on agricultural and rural development. To achieve this, we feel it necessary first of all to clarify the meaning given to certain terms, such as intensification and productivity, and to better understand the agrarian dynamics arising from increased land pressure.

The different channels of intensification and its links with productivity

Agricultural intensification is a concept that can be defined in a number of different ways, each giving rise to its own interpretations. We will conform to the definition adopted in rural economics which defines agricultural intensification as an investment in labour and/or capital per unit of area cultivated.

Based on this definition of intensification, we can identify a number of different channels. First, it can represent an increase in the labour invested in the area cultivated; this is the kind of intensification seen in Bamileke, and the kind that has made it possible to feed the very high population densities in South-East Asia. It is the main mode of intensification in non-industrialised countries, confirming Boserup's theory, which, like all great theories, demonstrates the obvious … once the theory has been formulated. Indeed, in those countries that essentially correspond to the least developed nations, recourse to capital is very limited, which means that intensification can only take place if the population density is high enough to afford the workforce this intensification requires. But faced with a problem as complex as agricultural development, we must beware of any simplistic determinism: while population density is a necessary condition for intensification in non-industrialised countries, this does not make it a sufficient condition, and this must lead us to examine the other conditions for agricultural intensification.

The other channel of agricultural intensification involves investment in capital, *i.e.* the acquisition of equipment, the construction of buildings, the use of agricultural inputs or development. This is the route taken by agriculture in industrialised countries such as France since the Second World War, to the extent that it is now very difficult to establish oneself in agriculture without considerable initial capital.

All the intermediate stages between these two paths are possible, such as in countries like Morocco or Tunisia, described as emerging, where we can see a modernisation of agriculture. In these countries, this modernisation is accompanied by the gradual replacement of labour by capital.

Whichever route is adopted, agricultural intensification is thus above all a process.

Productivity, meanwhile, according to Legay (1986), is an orphan term in the sense that it only has a meaning if it is qualified. In agriculture, for example, it is useful to distinguish land productivity from labour productivity; depending on the rarity and the strategic nature of these factors, farmers will aim to increase productivity in one area rather than the other.

Generally, agricultural intensification goes hand in hand with increased land productivity, *i.e.* higher crop yields. This increase is what makes the investment necessitated by the intensification worthwhile and ensures the sustainability of the process. It is also this dependency that often causes people to confuse the process with its result.

However, agricultural intensification does not always require an increase in labour productivity. While the replacement of labour by capital in the industrialised countries has led to a considerable increase in the productivity of labour, enabling less than 5 % of the workforce to feed the rest of the population and even export agricultural produce, intensification through labour on the other hand, as we will see, generally results in a drop in labour productivity, penalising developing countries in the international competition economic liberalisation forces them to engage in.

Agrarian dynamics and population density

Increases in population density modify the farming practices of rural societies. In tropical areas, several authors have tried to analyse and formalise this agrarian evolution. Ester Boserup, for example, in her analysis of agrarian dynamics focusing on increased land pressure, identifies different stages of this evolution according to the duration of the fallow period. These stages range from shifting cultivation with slash-and-burn to irrigated agricultural systems able to provide several crop cycles in the same year. Based on this general view of agricultural evolution, the historian Hopkins identified seven modes of cultivation in West Africa. Similarly, Ruthenberg established his famous agricultural intensity index based on the relative importance of the fallow period compared with the cultivation period (the 0-100 index corresponds to the percentage of the cultivated area in relation to the total area required by the system, *i.e.* the cultivated area plus fallow land).

In this view of agricultural evolution, the first stage considered is the slash-and-burn system. Was this historically the first stage to be adopted by farmers? This is debatable, and some authorities consider that in situations where security is threatened by wild animals or inter-ethnic conflict agriculture could have been settled and relatively intensive.

Nevertheless, slash-and-burn is a very ancient system that has been practised in most intertropical areas and is still in use in many regions, from Kalimantan to the Amazon via south-eastern Cameroon and the forested regions of Guinea (photo 1). It is the system used by pioneers exploring new territory, lending credence to its role as the first system used in the exploitation of forest land.

The system can be defined by a short cultivation time alternating with a long fallow period in which tree cover returns. The operation of the system was poorly understood until recently, and the practice is still judged harshly. It was thought for many years that what led farmers to abandon their fields after two to three years' cultivation to clear more land was the fall in the mineral and organic fertility of their land. However, work by researchers such as Moreau (1993) in Côte d'Ivoire has shown that the accumulation of fertilising elements and the reduction in soil acidity following the burning of the biomass accumulated in the tree cover during the long fallow period enabled a longer cultivation time than that usually adopted by farmers in systems with no land constraints. In these conditions, what led farmers to abandon their plots was above all the spread of weeds (de Rouw, 1991).

Photo 1. Slash-and-burn system in Guinea.

The long fallow period with tree growth eliminates these weeds, so that once the land is cleared crops can be cultivated without weed removal. This is supported by the absence of hœing tools in the original slash-and-burn clearing systems, where the only tools used were axes, fire and digging sticks.

If we now consider the performance of this kind of system, we see that crop yields are generally satisfactory. For example, with upland rice after clearing, yields of 2 tonnes/hectare can be obtained. But if this production is scaled up to all the land required for the system to operate, *i.e.* including fallow land, the productivity per hectare becomes much more mediocre, falling to about 0.2 t/ha.

On the other hand, when we evaluate the labour time required by these systems we see that the labour productivity is fairly good. We are thus dealing with an extensive system providing good labour productivity. On the basis of this observation, we can better assess the rationality of the practice from the farmers' viewpoint. In the general context of shifting cultivation with slash-and-burn, where population density is low, the farmer's goal is to emphasise the rarest and thus most strategic factor of production. Here this factor is labour, and we can thus better understand why farmers leave their fields as soon as the need to hoe and reduced yields lead to a drop in their labour productivity. We can also see why they would be reluctant to move to settled cultivation, the recurring goal of most agricultural projects and services.

But while the agronomic and economic rationality of these systems is beginning to be better understood, this does not apply to their ecological impact. These systems are considered to be responsible for the destruction of tropical forests. In the original system, the long fallow period allowed for tree cover to be restored – this was certainly not primary forest, but it did guarantee the continuity and sustainability of this mode of exploiting the habitat. This is proved by the fact that in many tropical regions agriculture has been practised for very long periods, sometimes since the Neolithic age.

However, the criticisms that are made of slash-and-burn cultivation from the environmental perspective are quite justified when the system evolves and degrades or, as in the Amazon, is used only as a stepping-stone towards replacing the forest with pasture land as quickly as possible.

Indeed, most of the advantages presented by the system disappear when land pressure leads farmers to extend their cultivation time by cutting into the fallow period. This situation occurs when Ruthenberg's agricultural intensity index exceeds 20, corresponding approximately to a population density of over 20 people per km^2 in tropical Africa (Jouve, 2001).

Once this threshold is exceeded, the fallow period is too short to produce enough biomass to restore soil fertility or, above all, eliminate weeds. The result is a drop in the productivity of the soil and of labour, together with the gradual degradation of the environment. In particular, extending the cultivation time affects the scope for tree regrowth and thus causes a fundamental ecological change, a *transition to savannah*; the original fallow period with tree growth is replaced by a grassy fallow period, which brings far less benefit than a return of the forest.

It can therefore be considered that one of the biggest challenges facing agronomists in tropical Africa is to find alternatives to slash-and-burn when the technique can no longer operate normally due to increased land pressure.

This increase is bringing about a transformation of cultivation systems, but as we have already seen this evolution can follow either Boserupian lines, *i.e.* gradual agricultural intensification accompanied by sustainable resource management, or a Malthusian path, leading to degradation of the productive capacity of the land. We have also seen that both these scenarios can be observed on the ground, raising the following questions: how can we reconcile these two opposing viewpoints about the agrarian dynamics at work in Sub-Saharan Africa, and how can we move from a regressive dynamic to an agricultural intensification that is sustainable in both agro-ecological and socio-economic terms?

The agrarian transition and the resilience of rural societies

Over the XXth century, countries in the South, and particularly in Sub-Saharan Africa, have seen demographic growth they have never experienced before in their history, with most of them seeing their population multiplied by nearly ten. Growth on this scale has profoundly changed the conditions under which agricultural land is exploited. The fallow period, which, as we have seen, was the primary means of maintaining soil fertility, has gradually been reduced, almost to the point of total disappearance in a number of African territories. This change in the relationship between population and cultivated land has occurred in too short a space of time for the rural populations concerned to be able to adapt their systems of cultivation to these new conditions of production. They have therefore held on to modes of exploitation that have become obsolete, gradually damaging their environment. This is the kind of situation that has been observed in Malthusian-type agrarian evolution, with a gradual decline in crops due to inadequate maintenance of soil fertility and increased pressure on natural resources, compromising their reproduction.

But as the worst is never the only option, some situations have also been observed where rural societies have reacted by adjusting the ways they exploit the environment in order to combat its decline and regenerate its productive capacity.

To illustrate this change in behaviour, we will look at two examples in the Sudanese Sahel.

The *zaï* technique involves digging small basins in degraded plots (*zipellé*) to regenerate the soil structure and help water penetrate (photo 2). A little organic matter is placed in these regularly spaced basins, in which millet or sorghum is sown in small holes (Rose *et al*., 1995). This practice considerably improves crop productivity, but it is labour-intensive, which explains the irregularity of this regeneration. Despite the labour cost, the technique has spread quickly in other parts of the Sahel affected by the same problems of soil degradation following a major growth in land pressure.

The other example comes from the Maradi region in Niger. Here too, following a rapid rise in the rural population, cultivated land has been extended to the detriment of rangelands and surrounding brush land. This extension has been accompanied by a significant drop in tree resources, which has strongly affected the operation of village agroecosystems. In response to the situation, the village farmers have changed their practices with regard to managing tree resources. Rather than mining the resource they have begun to engage in conservation management by protecting saplings growing in their fields. This practice, also known as *assisted natural regeneration (ANR)* (photo 3), has made it possible to replant many village territories in Niger and in other countries in the region where, like *zai*, it has spread rapidly (Joët *et al.*, 1998)

It is this change from a Malthusian logic to a Boserupian logic that we call the *agrarian transition* (fig. 1). It can happen at a more or less advanced stage of degradation, or even not at all if the degradation has become irreversible, which fortunately is fairly exceptional. This ability of certain rural societies to react to the degradation of their environment can be compared with the phenomenon of *resilience*,

Photo 2. Sorghum and zaï technique.

Photo 3. Assisted natural regeneration.

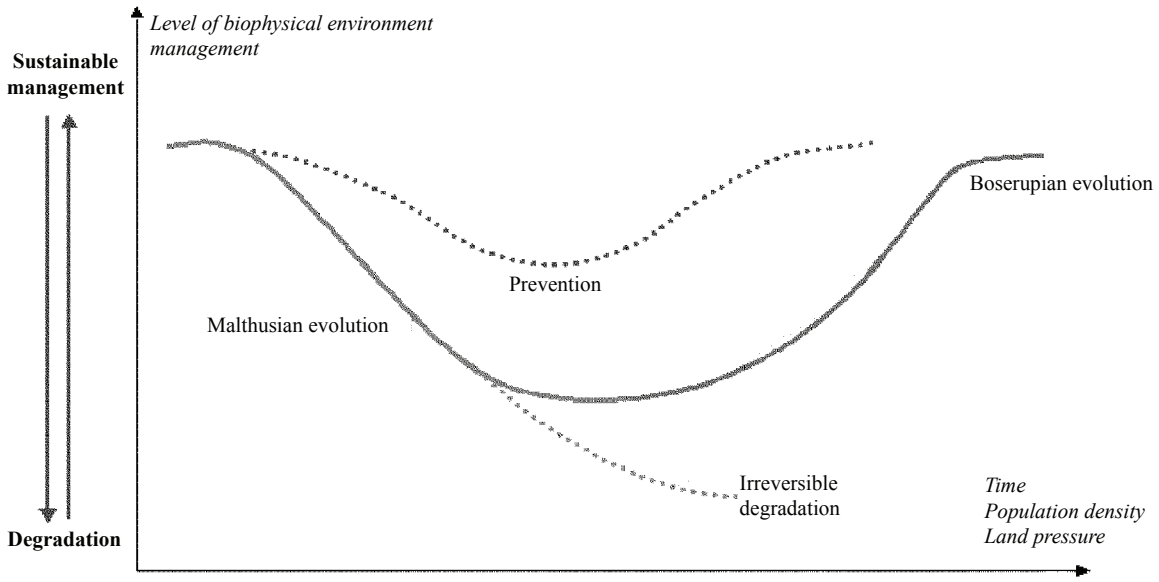

Figure 1. Agrarian transition diagram (resilience of rural societies).

which psychologists have borrowed from materials science to describe some people's ability to overcome the challenges they face.

The phenomenon is also comparable to the capacity of certain degraded biophysical environments to regenerate. In the same way as we talk about ecological resilience in this case, we can talk about societal resilience when a rural society finds within itself the resources needed to regenerate its degraded environment. The recent development of the Yatenga in Burkina Faso is very significant in this respect (Kaboré, 2005).

Strategies to accelerate the agrarian transition and promote agricultural intensification

If we can agree that the development of agriculture in Sub-Saharan Africa requires a change from a Malthusian logic, characterised by a mining approach to natural resources and the degradation of the environment, to a Boserupian logic of sustainable resource management and agricultural intensification, development strategies must aim to accelerate the agrarian transition between these two approaches.

The examples we have given to illustrate the concept of the agrarian transition show that one way of accelerating the change is to promote traditional knowledge and skills in order to mobilise rural societies' own endogenous ability to combat the degradation of their environment. But interesting though this route may be, we feel it is unlikely to be enough to face the huge challenge of transforming Sub-Saharan agriculture into a productive, sustainable operation. To define the strategies that will achieve this goal, it is also important to mobilise the knowledge we have acquired about the sustainable management of cultivated ecosystems in tropical zones and the conditions for agricultural intensification.

The first condition to ensure the sustainability of these ecosystems is an agroecological one. With the reduction or disappearance of fallow periods, other methods must be found to maintain soil fertility. These methods are known: combining crops with livestock to transfer fertility from rangelands to cultivated land and to recycle and recover harvest residues, as happens with

compost; combining trees with crops, *i.e.* agroforestry, enabling vertical transfers of fertility; the introduction of legumes into crop cycles and combinations to improve the nitrogen content of the soil; and finally, if other methods are inadequate to compensate for the minerals consumed by crops, the addition of fertilisers or soil conditioners from outside the system. But these methods are not independent of the economic conditions in which farmers find themselves, as we shall see below.

Another condition for the agroecological sustainability of cultivation systems in tropical zones is protecting the soil against physical damage and maintaining a sufficient level of organic matter. We know that cultivating the soil in these zones leads to a drop in this level which, if not controlled, is the origin of the vicious circle of soil degradation (Jouve, 2002). In theoretical terms, we are beginning to learn how to curb these forms of degradation and initiate a virtuous circle of soil management; in humid tropical zones, these methods are essentially based on soil cover, which can be achieved in a variety of ways but in particular by combining different crops.

But the development of sustainable agriculture that can satisfy the needs of a fast-growing population requires not only protection for the productive capacity of land but also an intensification of production. As land availability in Sub-Saharan Africa, while considerable, is not unlimited, it is important to increase soil productivity if the countries of the region are to ensure their own food security. But this intensification must also involve increased labour productivity.

When the majority of the African population was rural, an agricultural worker only had to feed two or three people, which was possible through manual agriculture. But as well as the overall increase in the population, there has been a significant rise in the urban population compared with the rural population. For the latter to be able to feed the former, farmers must improve the productivity of their labour. Initially, this necessarily involves animal power where possible, followed by mechanical power. It thus appears that the agrarian transition to be encouraged means passing not just from a Malthusian logic to a Boserupian logic but also from an intensification based essentially on labour to an intensification through investment in the means of production to increase the productivity of this labour.

We should also note that the growing importance of the internal market considerably changes the development prospects for agriculture in African countries, whose fate was long tied to exports at prices over which they had little control.

This thought-process about the intensification of African agriculture requires a more detailed examination of other factors that condition it than demographic growth.

We will limit ourselves here to restating the opposition between intensification and risk. This may be of various kinds: climatic, which explains the gradual extensification of production systems when aridity increases; phytosanitary, when disease, weeds or pests threaten production; and finally economic, when the conditions of remunerating labour and of farmers' investments are uncertain and insufficiently assured. Conversely, when farmers can benefit from guaranteed prices and opportunities, as was the case with cotton production, they are able to intensify their production systems with a degree of efficiency comparable with European farmers when the CAP (Common Agricultural Policy) ensured guaranteed prices and opportunities.

It is therefore legitimate to question whether the liberalisation policies imposed on African states are well founded. These policies, by making inputs more expensive, reducing produce prices and increasing their fluctuation, cut farmers' revenues and their ability to invest and permanently diminish their capacity and propensity to intensify; moreover, the fall in farmers' revenues and rise in rural poverty can only reinforce the practice of mining natural resources and hinder the emergence of a productive, sustainable agriculture in the South.

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Agrarian dynamics and population growth in Burundi: agroecology before its time[1]

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Burundi is a small country of 27,000 km^2 with eight million inhabitants, whose landscape is generally mountainous and lies between 1,000 and 2,000 metres above sea level. The picture one can paint of Burundi, like neighbouring Rwanda, is one of densely populated countryside (200 inhabitants per km^2 in 1990, close to 300 today), that density representing rural density, since the towns are of a modest size in both countries. Settlements are scattered, with very small agricultural production units, measuring on average less than one hectare. Exclusively manual and mainly centred on food crops, farming in Burundi might appear, to the uninformed observer, to be a picture of "traditional" farming directly inherited from the past.

However, the agrarian history of this little country in the African Great Lakes region has an exceptional amount to teach anyone with questions about the future of farming and food production in this part of the world, and food production for mankind as a whole.

A diachronic approach to the agrarian history of Burundi reveals that it has seen two major agricultural revolutions which have deeply transformed its farming, not through recourse to fossil fuels and industrial inputs, like the countries of the North, but almost exclusively based on organic mechanisms and human ingenuity. Long before the term even existed, Burundian peasant farmers invented agroecology and made biomass management the central issue both for the production systems in place and for the social relations forged between actors.

In this way, Burundi achieved food independence in the late 1940s, allowing it to cope with population growth in the second half of the XXth century which might have been maintained had it not been plunged into civil war in 1993.

1. This text was first published as a chapter in the book by B.A. Wolfer (dir.):*Agricultures et paysanneries du monde. Mondes en mouvement, politiques en transition.* Permission granted © Quae Editions, 2010.

Epistemological obstacles

When I arrived in Burundi, I was immediately struck by a feeling of unease linked to the following question: at the time, anyone setting foot in the country had to take one of two entry points, a kind of required passage. First was the ethnic variable, the distinction between Hutu (a group thought to be of agricultural origin) and Tutsi (a group thought to be specialised in pastoral activities) being supposed to shed plenty of light on farming matters; second was population "pressure", which for some, neo-Malthusians, was the source of all ills, and for others, more inspired by the theories of Boserup[2], the motor of change. There are not many parts of the world where advocates of these "opposing" theories have come in more direct opposition, in particular in the agricultural sphere.

From the outset of this research, was it necessary to conform to this line of thinking and approach the issue of Burundian agriculture based on these perspectives that were considered indispensable? I decided, there and then, that the answer was no. I did not have many arguments to justify my choice, but some sort of intuition led me to distance myself from them. So I disposed of these two entry points. Along the way, these two "interpretative keys" proved instead to be epistemological obstacles, in the full sense of the term. The choice I had made not to take this path proved justified, and enabled me to formulate new hypotheses and thus to take a new approach to agriculture in this region of the world.

By disposing of these questions, I made a number of enemies within the community of researchers and experts working in these regions. I had to work rather solitarily, mostly with students of the Burundi Faculty of Economics and with farmers themselves, to try to come back to looking at the facts, to talk to people and to attach the utmost importance to agrarian history, since it was in the name of that history that the most devastating of ideologies were created, then renewed and expanded upon in recent years.

The aim, then, was to try to understand this country's agricultural development, viewed as a long-term process (it is a country whose agrarian history spans two thousand years), and to attempt to reconstruct what had happened, to gather up the facts, to interpret them and perhaps to give a different interpretation to the successive crises suffered by the country, each crisis making way for a complete transformation of the agrarian system.

The results of that research are what I will try to present here. Without dwelling on methodological aspects or what concepts were used, I will stress above all what might be retained from this agrarian dynamic, coming back, in the conclusion, to these two epistemological obstacles which I circumvented at the start.

The antiquity of agrarian history in this region of the world

It is now almost certain that agriculture and pastoralism have been associated for 2000 years in this region of the world[3]. This may seem insignificant, but if one looks at the ethno-political conflicts of recent decades, at times still "explained" in terms of the historical subjugation of the Hutus, considered a group of indigenous farmers, by a group of non-indigenous herdsmen, the Tutsis, discovering that the association between agriculture and livestockdates back 2,000 years in this region seems important to me.

Some 1,500 or 2,000 years ago, then, an agro-pastoral system emerged. Agricultural activities were based on the cultivation of cereals – sorghum and finger millet[4] – continuous cultivation which involved, not slash-and-burn systems with a long rotation period, but tillage systems involving

2. Boserup E. (1965). *The Conditions of Agricultural Growth: The Economics of Agriculture under Population Pressure*, 124 p., London and New York.

3. Schoenbrun D.L. (1990). *Early History in Eastern Africa's Great Lakes Region: Linguistic, Ecological, and Archaeological Approaches, ca. 500 B.C. to ca. A.D. 1000*, Los Angeles, USA; Van Grunderbeek M. C. and Roche E. (2007), Multidisciplinary Evidence of Mixed Farming during the Early Iron Age in Rwanda and Burundi *in* Denham T., Iriarte J. and Vrydaghs L. (ed.) *Rethinking Agriculture: Archaeological and Ethnoarchaeological Perspectives, One World Archaeology*, nº 51, California: Left Coast Press, Inc., 299-319.

4. *Eleusine corocana*, a cereal very likely to have been domesticated in East Africa.

digging and successional sowing over short periods. At the same time, sedentary livestock emerged, producing both milk (part of which was turned into butter) and meat, and providing animal excrement which was meticulously collected to fertilise the arable land, in a real association of agriculture and livestock. These sedentary agricultural and livestock activities were pursued by people who spoke the same language and lived in the same hills, in settlements located on the tops of those hills.

Towards the XVIIIth century, both Burundi and Rwanda witnessed what I have termed an "agricultural revolution", in other words, a series of highly significant transformations to farming, social relations and society as a whole.

A little-known agricultural revolution radically changed the agrarian system in the XVIIIth century

Widespread cultivation of plants from the Americas and the introduction of a new agricultural calendar

Maize and beans[5] appeared in Burundian farms and very quickly spread throughout the region. At the same time, double-cropping developed, in other words, farmers were able to harvest two crops a year on the same plot of land. This, too, was a major innovation.

In this region, where a double harvest is made possible by precipitation levels (it rains from September/October to May/June), this was not the case prior to the introduction of plants from the Americas: a single cycle of sorghum or finger millet was cultivated each year (these cereals having a relatively long cycle here). The introduction of new plant material from the Americas enabled farmers, by means of an innovation process which it is hard to reconstruct precisely, to put in place a far more intensive agricultural calendar, with a cycle of maize combined with beans in the first part of the rainy season, followed immediately by a cycle of sorghum. Whereas up until then sorghum had been planted at the beginning of the rainy season, sorghum sowing was consequently put back to mid-season in order to be able to fit in a crop cycle of the new plant material before it. All of this took place in the XVIIIth century.

The result of this transformation was a twofold increase in overall labour productivity. At the time, it was a significant advance. A working person was thus able to produce the equivalent of 20 quintals of cereals and pulses per year as a result of these changes, where he had previously produced scarcely more than ten (Cochet, 2001).

Improvements to associative practices between agriculture and livestock

Another significant change in this period involved improvements to associative practices between agriculture and livestock, with the increasingly meticulous recovery of animal excrement and longer stabling periods. Cattle would sleep in the farmyard and their dung would be collected by hand each morning, to be spread on the cultivated land. During the long rainy season, the settlements being located on the hilltops, little channels were built to carry the nutrient-rich rainwater to the cultivated plots.

In this emerging new society, cattle played an absolutely central role, from two points of view. First, they were the only accumulable asset, and thus represented capital in both the literal and the figurative sense, so that what distinguished one farmer from another at that time was the size of his herds. Second, cattle were the medium for fertility transfers from the saltus (pastures) to the ager (crops). For that reason, a farmer who had a large herd was rich not only because he possessed a large herd, but because he had access to large quantities of recoverable cow dung, which would enable him – or others, through clientelist relations – to cultivate bigger plots offering higher yields. Thus, from that time forth, cattle were right at the heart of mechanisms of accumulation and differentiation between farmers.

5. Of the genus *Phaseolus*; beans of the genus *Vigna* date back much further in Africa.

Clientelistic relations and tributary relations

The XVIII[th] century saw the curious spread of *relations of clientelism* based essentially on the management of fertility, in this case organic manure. What were known as "cow contracts" became increasingly widespread. These were contracts binding the owner of a large herd to someone who had very few or no cows, and gave those with no cattle, in exchange for a fee and/or services, access to a heifer[6], and thus to the fertility transfers which cattle enabled. These social relations thus allowed the association between agriculture and pastoralism to spread well beyond what would have otherwise been possible given the very unequal distribution of cattle ownership.

In this period, social relations of a tributary nature also emerged.A tributary society was put in place in Burundi, whereby a kingdom (as in neighbouring Rwanda) and the new ruling class (princes of royal blood, priests, seers, ritualists, *etc.*) lived off the levying of a tribute. Its legitimacy was, to some extent, tied to the fact that the King was guarantor of the fertility of the land, cows and women of the kingdom: an entire politico-religious aristocracy emerged and, curiously, all the agrarian rites – that is, all the religious aspects of that society – revolved around the new agricultural calendar and the possibility of having two harvests a year on the same plot of land. The sorghum plantings having been postponed to the middle of the rainy season, the date of those plantings (late December) became a national festival, accompanied by a strict ban on planting sorghum before that date[7]. The whole politico-religious structure which was put in place in this period crystalised the agrarian transformations which had emerged throughout the XVIII[th] century.

These multiple technical, social and political transformations made possible continuous population growth throughout the XVIII[th] and XIX[th] centuries. It was a period of expansion and growth. Population growth was obviously very slow (no more than 0.5 to 0.75 % per year), but it was almost continuous[8] (see Figure 2).

At that time, it is difficult to know precisely what was meant by the categories Hutu and Tutsi. They appear to have been social categories: people with large herds, who were therefore at the top of the social pyramid, considered themselves, and were considered, Tutsis, while those who had few cattle considered themselves, and were considered, Hutus. These categories were therefore not "ethnic", since an important farmer who through misfortune (*e.g.* lightning) lost his herd was "downgraded" to the category of Hutu. Thus it had little to do with ethnic distinctions, although property (cows) was obviously, like identity, passed on in a hereditary manner, which here meant from father to son.

1891-1944: Fifty years of agrarian crisis

At the end of the XIX[th] century, this system suffered an extremely sudden crisis which would last more than 50 years, from 1891 to 1944, over five decades of very severe crisis. Population growth came to a standstill during these years, meaning that the country was regularly ravaged by famine and epidemics. This crisis therefore signalled a break with the previous two centuries of agricultural growth (Figure 2).

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6. Chrétien J.P. (1984), Agronomie, consommation et travail dans l'agriculture du Burundi du XVIII[e] au XX[e] siècle, *in* Cartier M. (ed.) *Le travail et ses représentations*, Paris, 123-178. Botte R. (1969), Burundi: la relation ubugabire dans la tête de ceux qui la décrivent, in "Les relations personnelles de subordination dans les sociétés interlacustres de l'Afrique centrale", *Cahiers d'Etudes Africaines*, Vol IX.3, n° 35, 363-371.

7. Bahenduzi M. (1991), *Le rituel du Muganuro dans l'histoire du Burundi des origines au XX[e] siècle*, doctoral thesis. University of Paris 1 Panthéon-Sorbonne, CRA, Paris.

8. Thibon C. (1989), L'expansion du peuplement dans la région des Grands Lacs au XIX[e] siècle, in *Canadian Journal of African Studies, vol. 23, n° 1*, Association canadienne des études africaines, 54-72.

9. Thibon C. (1999), *Recherche en histoire rurale. Sociétés rurales en modernisation. Pyrénées XIX[e] siècle, Burundi XX[e] siècle. Une histoire sociale du politique. Tome 1: Synthèse Burundi: Croissance, transition démographique et crises socio-politiques au Burundi 1880-1993, Une population prise au piège d'une fatalité ou de dérives socio-démographiques modernes*, HDR qualifying thesis for research directorship, Université de Pau et des pays de l'Adour, Pau.

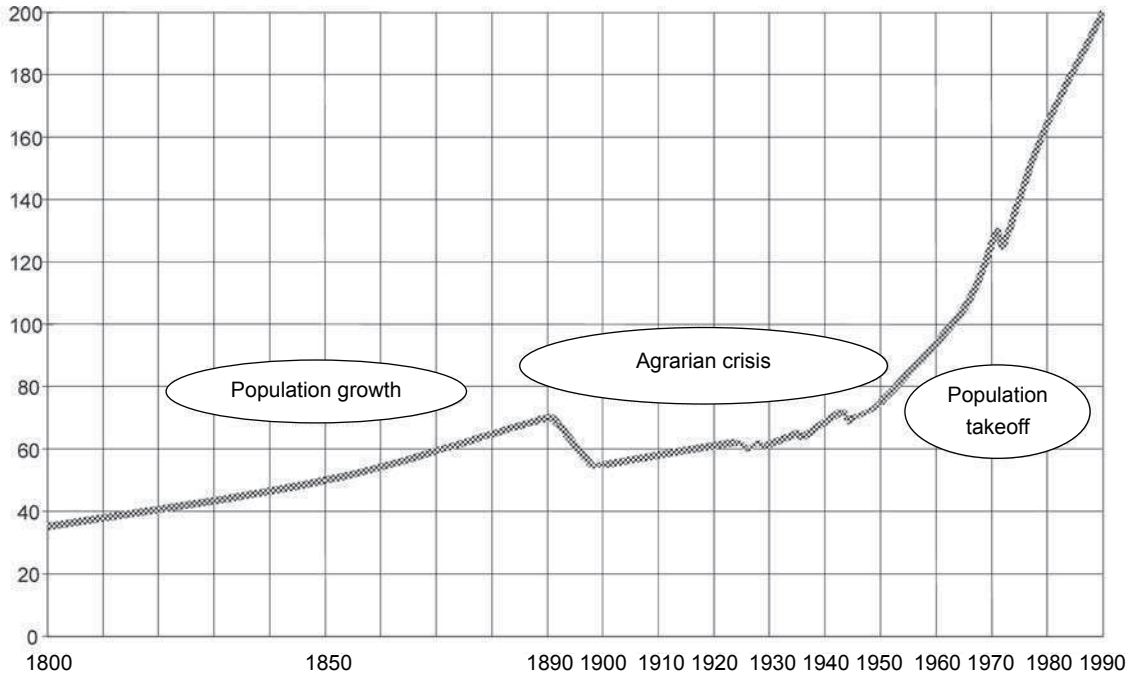

Figure 2. Changes in population density in Burundi from 1800 to 1990, showing slow population growth in the XIXth century, major crisis until the early 1940s, then sustained growth. *Source:* H. Cochet, based on the work of Christian Thibon (1999)[9]. The diagram shows a hypothetical reconstruction of XIXth century population growth based on a slow progression of 0.5 to 0.75 % per year.

In order to explain and interpret this crisis, the period in question needs to be split into two.

To begin with (in the first 25 years), it was a Malthusian crisis. It was triggered by epizootic diseases: cattle in Burundi and Rwanda were decimated by rinderpest, foot-and-mouth disease and trypanosomiasis (sleeping sickness). Evidently, with the disappearance of the cattle (up to 90 % in some areas), the entire structure collapsed, since cattle were both farmers' capital and the medium for fertility transfer which made that farming sustainable. If we seek to understand the reasons for this crisis, we can show that it results from a certain "ceiling" being exceeded, that is, the maximum capacity of this agrarian system to feed a given population. It can be estimated that, at that time, approximately 12 hectares per family were required for the system to be sustainable, taking into account the area of pasture needed to maintain a small herd, itself necessary to renew the fertility of the land, which was intensively cultivated using the double-cropping system. Bearing in mind that each family could contain five or six people (lineage-based social relations, and with them the extended family, having long since become looser), 12 hectares per family gives a possible population density of 50 inhabitants per km^2, which was quite considerable at the time. By 1890, that population density would appear to have been greatly exceeded, reaching 65 or 70 inhabitants per km^2. The earliest census available, showing a population density of 55 inhabitants per km^2, is that conducted by the settlers in the first years of the XXth century, after the first great famine. It is therefore certain that the ceiling had been greatly exceeded and that population density was established well above what the agrarian system could sustainably feed. The consequences of that overpopulation are easy to understand: in order to feed a population that was continually growing, it was necessary to expand the areas under cultivation at the expense of pasture land, while at the same time there was an increased need for animal dung to restore the fertility of the fields. With everyone striving to have as many cattle as possible (multiplication of "cow contracts" for the worst off, raiding of neighbouring lands for the princes), the result would have been widespread overgrazing, a kind

of "tragedy of the commons"[10], where it was in the individual interests of each farmer to accumulate cattle in an attempt to curb the unavoidable reduction in the ratio of animal dung to area under cultivation. This crisis of widespread overgrazing would explain, to a large extent, the suddenness of the epizootics: the fact that the cattle were killed off so violently by microbes, despite some of them having long been present in the region, shows that they were very weak and unable to resist the microbial attacks.

Although European colonisation took place in this period, the crisis in the agrarian system was first and foremost an endogenous crisis, or at least it can be interpreted as such in its initial stage.

In a subsequent stage, colonisation played a decisive role in prolonging the crisis. The reason it went on for so long was the colonial pressure exerted on peasant farmers from the first decades of the XXth century. Burundi and Rwanda were colonised by Germany, but the Germans did not have time to put in place a proper colonial administration because they were expelled from the region by the League of Nations following their defeat in the First World War. In 1918, the League of Nations handed Rwanda and Burundi over to Belgium, and it was the Belgian Government that would put in place this colonial system, in the 1920s and 30s.

Colonial policy would worsen and prolong the crisis. The mechanism was quite simple: capitation (poll tax), compulsory coffee-growing, all manner of colonial corvées, and compulsory food crops meant an increase in levies and a considerable diversion of labour, at a time when peasant farmers were suffering a serious crisis. There is no doubt that these new pressures worsened the crisis. It is worth remembering that, at that time, anyone unable to pay their tax was subjected to corporal punishment. In order to be able to pay this tax, whose relative weight went on rising in relation to what taxpayers could expect to sell, people had two options: they could either sell their last cows or goats, further worsening the process of decapitalisation brought about by the crisis, or flee the country to take refuge in the British colonies, where it was easier to hide or gain access to paid employment. The result was a labour drain, which increased the tax burden on the workforce that remained in the country.

Another aspect of colonial policy, which was to leave lasting marks, was the purely ethnic interpretation which missionaries and colonial administrators made of the society they encountered. According to the dominant ideology of the 1930s, any difference between social groups could be explained solely by means of race, and, what is more, races were hierarchical by nature. A whole body of literature appeared during this period to explain how the Hutus were an ethnic group of farmers which had been subjugated by an ethnic group of pastoralists, considered superior, the Tutsis. This ethnic interpretation was facilitated by the ravages of the agrarian crisis mentioned previously, because the society discovered by the settlers was, in actual fact, a society where only a small elite still had cattle, since 90 % had been decimated. The only families who had managed to keep or renew part of their livestock were those who previously had the most, those who had several herds looked after by herdsmen in different places and had therefore been able to spread the risk, while the vast majority of the population had lost all their cattle. But the settlers interpreted it as follows: those who still had cattle were presumed to be a "pastoral people", while those who had none were assumed never to have had any, and were therefore a "farming people". This view, ignorant of the past, was not only wrong, but the colonial administration decreed that this minority of "pastoralists" was endowed with superior qualities and was therefore predestined to rule over the others. It was from among their ranks, then, that the young men trained to become the "indigenous" fraction of the colonial administration were chosen: policemen, tax collectors, nurses, agricultural advisers, veterinary officers, *etc*.

That half-century (1891-1944) saw five successive famines. Each time population growth resumed its rhythm, once more the population was ravaged by deadly famines, and this went on until 1943-44, the last famine in Burundi's history. In 1945, population density was still 55 inhabitants per km^2.

10. In the sense of G. Hardin, The Tragedy of the Commons, in *Science* (13 December 1968).

Agrarian transformations in the second half of the XXth century

The end of the colonial period signalled a recovery from the crisis. Here again, the timeline that can be established for the agrarian system does not coincide with the political timeline. The recovery from the crisis and what I shall call the triggering of a new agricultural revolution did not coincide with independence, but occurred a good ten years earlier, as things began to change once again from 1945 onwards.

From 1944, the population curve took off (figure 2). In 1960, the threshold of 100 inhabitants per km^2 was reached, and all the experts sounded the alarm that the system had reached capacity and we were heading straight for a new imbalance between population and resources; Malthusian models were the order of the day for setting all the warning lights flashing. In the 1990s, the 200 inhabitants per km^2 mark was reached. Even so, the country achieved food self-sufficiency, suffering no more serious food crises since 1943-44. The population trebled, food production did too, and, in addition, both Burundi and Rwanda became exporters of high-quality arabica coffee and tea. This spectacular growth took place with no industrial inputs: no fertilisers, no plant-protection products, no new tools except the factory-produced hoe making it unique enough to be highlighted. Burundi's production saw exponential growth, at the same pace as its population, with no new inputs, and it enjoyed food self-sufficiency which would still be the case today if it had not been plunged into civil war in 1993.

A major upheaval then took place and a series of highly significant transformations which I will attempt to outline below.

Banana plantations

Anyone who travels through the hills of Rwanda and Burundi is struck by the ubiquitous banana trees. These hills present a very verdant landscape, where the upper half of almost every hill is covered in banana trees. Today they hold an important place in the Burundian and Rwandan landscapes, but, interestingly, this is a recent phenomenon. The Burundians were familiar with the banana tree but, up until the 1940s, they cultivated them very little. One of the first dynamics of the second half of the XXth century was that the hills became partly covered with banana trees.

From a genetic perspective, these are highly original cultivars. They are "dessert bananas" (genotype AAA), rather than "plantains". Yet these cultivars are not consumed as fruit, but solely in the form of "banana beer" (the fermented juice). The bunches of bananas are picked; then, after a few days in which the bunches are buried, bananas are peeled; they are placed in a kind of macerating trough, to which water is added; then they are worked to try to remove as much sugar as possible. There is demand for this product alone: the banana juice, which will go on to be fermented to produce "beer". All of the crop waste – the trunk of the banana tree, its leaves, the stalks of the bunches, the banana skins and the banana paste after the juice has been extracted – is returned to the soil, *i.e.* scattered around the banana plantation.

An agronomic analysis of this cropping system reveals how remarkably efficient it is. An analysis of the minerals in a plot cultivated using this system gives a balanced result because there is practically no loss of minerals: in the banana juice, there is little more than sugar (carbon), water and vitamins, so practically no nitrogen, phosphorus or potassium (NPK). All of these minerals are returned to the soil. Because banana plantations are also very efficient at preventing run-off and leaching, here is a cropping system which, for the first time in Burundi's history, does not require animal dung. As far as carbon footprint is concerned, banana plantations act as carbon sinks, and nearly all of that carbon, with the exception of the fraction contained in the juice, is returned to the soil. They therefore have an overwhelmingly positive carbon footprint, which is another unique characteristic of an agrarian system in which animal dung has become extremely rare: banana plantations do not require it and are themselves biomass-producing systems, accumulating carbon each time the waste is returned to the soil. The result is a spectacular improvement to the soil of banana plantations.

Another characteristic of this cropping system is that it is also highly efficient from a microeconomic point of view. All the calculations carried out, for all the regions of Burundi, show that whether it is evaluated on the basis of the wealth created per unit of area (value added/ha) or the wealth created per day of labour devoted to this cultivation system (value added/day of labour), this cultivation system is the most efficient from a microeconomic perspective (Cochet, 2001).

All of which goes to explain why, throughout the second half of the XXth century, farmers did all they could to expand their banana plantations as much as possible.

Intensification and complexification of crop combinations

On the other plots of their farms, farmers planted increasingly complex and sophisticated crop combinations, with sometimes as many as seven or eight different species on the same plot, resulting in a sort of "muddle" that would make any agronomist's head spin. But it was an organised, managed muddle, where not a single square centimetre was wasted, not a single ray of sunlight touched a leaf before touching the ground and not a single cubic centimetre of ground was not taken up by the roots of such and such a cultivated plant.

This sophistication of crop combinations was quite spectacular and was the result of a process of labour intensification of cropping systems. It occurred both on the hillsides and in the lowlands separating each topographical unit – each hill – from its neighbour.

Coffee

In the colonial period, coffee was a compulsory crop. The coffee was purchased from households so that they could use the money to pay their poll tax. From the 1950s onwards, the relative price of coffee became advantageous to farmers. For the first time in their lives, they found that coffee was a source of purchasing power (it would remain so until the late 1970s) and they deliberately set about increasing the areas under coffee cultivation.

Coffee was not the only woody species to be planted in the hills of Burundi. Besides tea, which replaces coffee above an altitude of 2,000 metres, many useful trees were planted by farmers within their banana plantations (fruit trees) or on the edge of their plots (*eucalyptus*, *grevillea*), so that in places the Burundian landscape takes on a wooded appearance that is all the more remarkable given that this tree cover became more dense as population "pressure" increased, contrary to an idea firmly rooted in people's minds.

This series of transformations at individual farm level, in a context where farm areas were decreasing as population density increased and farms were divided up between heirs, enabled an overall increase in production per unit of area, and explain how a 50 % increase in cultivated areas (between 1950 and 1990) could have led to a 150 % increase in food production (in addition to large-scale production of coffee and tea). An increase in the number of crop cycles (both on the hills and in the lowlands) and in the complexity of crop combinations; the development of banana plantations and the transformation of fertility-renewal methods; labour intensification; and, lastly, the doubling or trebling of food production: all of this amounted to a new agricultural revolution, yet with no industrial inputs – no tools, no fertilisers, no plant-protection products – a glimpse of the "doubly green" revolution which some experts have their hopes set on today[11].

This spectacular development led many researchers, academics and experts to interpret the evolution of Burundian agriculture by stressing the theories developed by Ester Boserup from 1965 onwards. In reaction to Malthusian and neo-Malthusian theories, Boserup had produced a model in which "population pressure", rather than being the source of all ills, was considered the driving force behind development: it was "population pressure" that forced people to intensify and "population pressure" that explained this high growth of production.

11. Griffon M. (Ed.), 1996. *Vers une révolution doublement verte*, Fondation Prospective & Innovation, CIRAD.

Admittedly, population growth went hand in hand with these transformations, since smaller and smaller production units meant that farmers intensified out of necessity. But this model of interpretation proves completely ineffectual when it comes to explaining why this process did not get started sooner and what its limits are or what crises it can withstand.

Why did this spectacular development process not get under way until the second half of the 1940s? The answer is, quite simply, because it was held back by colonial pressure. The fact is that all the elements of this transformation of the agrarian systems were slowly put in place in the 1920s and 30s, but in a rudimentary fashion on each farm. At that time, farmers were required to plant coffee in order to pay their tax and to devote 100 to 150 days of labour per year to "colonial corvée", so that although all the elements of this new agrarian system were present in the Burundian countryside well before the 1940s, that development was impossible while colonial constraints remained.

The end of the 1940s was marked by the abolition of forced labour and compulsory food crops, and by a context of relative prices where coffee became a source of purchasing power. Thus the easing of colonial pressure was a first *sine qua non* condition for these transformations to flourish.

Meanwhile, the labour force which had emigrated to the British territories returned en masse, beginning as early as the 1950s and, more decisively, after independence (1962). Hundreds of thousands of Burundians who had fled their country returned to their hills and set about devoting most of their time to managing their little patch of land.

Another necessary condition for this process was to maintain, or increase, the scattered nature of settlements. This new management of available biomass and the creation of banana plantations around farmers' homes could not have taken place in the context of nucleated settlements. Fortunately, attempts at villagisation, very much in vogue in the 1970s, both in this region and elsewhere, failed in Rwanda and Burundi. That failure was partly due to the fact that people were sufficiently attached to their banana plantations to steadfastly refuse to be resettled. Villagisation would have made the anthropisation of these lands impossible, or far more laborious.

Finally, emphasis should be put on the relatively egalitarian nature of this development process. Since in most cases the accumulation of capital meant the accumulation of biomass – people's capital being their banana plantation and the carbon sink it represented – that accumulation was necessarily slow and continuous, and did not lend itself to processes of despoilment or sudden accumulation, in particular through market trading.

Limits on this process

Concerning the banana plantations

The progressive anthropisation of the land by means of this cultivation system based on banana plantations was subject to two kinds of limitation. Although the consumption of fermented banana juice plays a not insignificant role in adult calorie intake, that consumption was not limitless and urban markets were a poor outlet. A second, agronomic limit was the fact that the centrifugal expansion of the banana plantations and the accompanying anthropisation of the land slowed down on the slopes, partly because the soil became more and more desaturated and acidic as one descended the slopes, and partly because, to set this process in motion, the animal dung was extremely valuable when the first banana trees were planted. Once there were scarcely any cattle left in the more densely populated areas of Rwanda and Burundi, it was no longer possible for the animal dung to play this *starter* role in the setting-up of the banana plantations, amounting to a second limit on the expansion of the banana plantations.

Total absence of inputs

It is a virtue of this development that such a feat was achieved with almost no industrial inputs and with an emphasis on the organic processes which are today the subject of agroecology theories.

But one should not be too quick to rejoice about the intrinsically "organic" nature of this development. For it is clear today that Burundian farmers will be unable to take this intensification process any further without having access to a minimum of carefully used inputs (fertilisers, plant-protection products) and a wider variety of tools (even if they remain manual). The extreme lack of inputs available to Burundian farmers today puts a fundamental limit on this process.

Concerning coffee

Coffee was one of the mainsprings of this development, but also one of the main stumbling blocks. Coffee itself was not the issue, but the fact that it was compulsory for Burundian farmers to grow it, which is something quite different.

The cultivation of coffee plants was made compulsory in the 1930s, and the cultivation method has changed little since then. Coffee had to be grown as a pure crop, on land often determined by the authorities (for a long time, along the roadsides); pruning had to be carried out a certain number of times, at regular intervals; and, above all, the coffee had to be *mulched*, which meant spreading a 20 cm layer of fresh organic matter over the coffee plot each year, at the end of the rainy season (the recommended amount being 20 to 25 tonnes of dry matter per hectare!). This covering of organic matter has various agronomic benefits: it restricts evaporation during the dry season; it provides effective protection against erosion and run-off; it smothers weeds; and it is an outstanding source of fertility, because this organic matter decomposes to the benefit of the coffee.

In the colonial period, roads were built across all the hillsides of Burundi and Rwanda, and farmers were required to plant coffee on either side of the roads. An inspector would pass by in his jeep or on his motorbike to check that the mulching had been properly carried out and, if he was in any doubt, he might get out of his car and insert a brand-new pencil into the *mulch* down to the soil, without encountering the least resistance. If that was not the case, the farmer was subjected to corporal punishment. Since then, little has changed: in the 1990s, mulching was still compulsory and the corporal punishment had merely been replaced with fines.

Today, this method of coffee cultivation poses many extremely serious problems. Where is this biomass to be found in farms that today cover less than one hectare? First, in the banana plantations: it seems natural for part of the crop waste from a banana plantation to be transferred to a coffee plot; but when that is not enough, there must be recourse to all the plots under food crops. So the second flow of biomass to emerge at the heart of each farm involves all the waste from its food crops, which is transported to the coffee plantation: the canes and stems of maize and sorghum, the haulms of sweet potatoes and beans (including the roots that are pulled up), and all the weeds. If that is not enough, farmers may resort to the last few acres of residual grazing land. In the most densely populated areas of Rwanda and Burundi, there is little pasture land left, so here, a ban on grazing these pastures must be imposed (which means getting rid of the last goat or cow), in order to scythe them and transfer the biomass obtained to the coffee plot.

This standard cultivation method leads to the emergence of multiple flows of biomass within the farm, all of which converge on the coffee plot. The intensity of these flows depends, first, on the farm area and, second, on the ratio of mulch-producing area to area under coffee, *i.e.* the relative position held by coffee in the farm's useful agricultural area. It depends also on the resources which farmers have to purchase biomass, there having emerged a veritable carbon market as this resource becomes increasingly scarce.

These new centripetal flows to the benefit of coffee and at the expense of all other plots weaken farms considerably. All that I have said higher up about banana plantations ceases to apply if the carbon, rather than accumulating on site, is transferred to the coffee plantations. The agronomic and economic effectiveness of this "banana plantation" cropping system is therefore directly threatened by the intensity of transfers to coffee plantations. As regards the complex food-crop combinations which farmers have introduced, it is clear that transferring all the crop waste, sometimes including part of the root system, multiplies by a factor of two or three the amount of minerals lost by these plots. As regards residual grazing land, it accelerates the disappearance of livestock and hence the fertility transfers which it was, and at times still is, able to offer, to the benefit of the cultivated land.

It is clearly apparent, then, that this unilateral policy (the imposed method for coffee cultivation) has become a threat to the farm as a whole and, by extension, to the entire agrarian system. This entirely obsolete cultivation method has become not only an agronomic dead end, but also an economic and social one.

In Burundi, biomass – carbon – has had a market price since the 1980s. When the poorest farmers have nothing left to sell, they sell their biomass (their crop waste, weeds, *etc*.) to their neighbours who have the means to buy it. Not only has biomass acquired a market price, it also has a colossal opportunity cost. This opportunity cost means the end of livestock; it means lower yields for food crops, since the loss of minerals undermines the renewal of fertility on those plots; and it means the reduced effectiveness of the "banana plantation" cropping system. This opportunity cost is thus entirely disproportionate, and calls into question both coffee cultivation in Burundi and the agrarian system as a whole.

Coffee cultivation is called into question all the more by producers as movements in the relative price of coffee make its production financially less and less viable. As a result, farmers are increasingly hesitant about sacrificing their biomass for a crop which gives them less and less of a return.

What is the explanation for such an inappropriate cultivation method being maintained for so long, and for this single, standardised method to have remained compulsory? Asking this question in the early 1990s in Burundi was no easy matter. Although it was clearly one of the most serious issues for Burundian agriculture, practically no research had been carried out on the subject. Merely by questioning this cultivation method, on strictly agronomic grounds, one aroused fears and opposition of a highly unscientific nature.

Coffee did, after all, account for 80% of export revenue. It was through export duties that the State coffers were filled. Levies on exports and international aid were what enabled the Burundian Government to function. The power in Burundi having been seized by a small minority – a political

minority – questioning this cultivation method was perceived by all the leaders and scientists of both countries as tantamount to questioning the country's entire economy and, more specifically, the State budget. In other words, it was impossible at the time, despite the agronomic and economic evidence.

Conclusion: carbon at the heart of development

To conclude, I would like to come back to the two "traps" which I sought to circumvent in my approach to Burundian agriculture: population "pressure" as a way in to agrarian systems, and the ethnic variable.

As far as population pressure is concerned, the debate between Malthus and Boserup is still omnipresent in Burundi, in the scientific, academic and political spheres. Malthusian theories were behind the crisis scenario that was awaited since the 1960s. But when the crisis didn't happen, the alarm went on being sounded over the following decades, without understanding the reasons behind the intensification processes that were taking place.

To the neo-Malthusians, population pressure was the cause of all ills, because it led to erosion, deforestation and the cultivation of the steepest slopes; so it was this population pressure that would be the cause of the crisis. To try to anticipate the crisis, since it was not possible to combat population growth - the Catholic Church being strongly opposed to birth control - it was necessary to "combat" erosion, to "combat" deforestation, and so on, the implication being that the cause of the crisis was agriculture itself, and hence peasant farmers and the intensification they had carried out. Yet everything about the Burundian landscape indicates the opposite: it is the least densely populated areas that show signs of erosion, deforestation and environmental degradation. Meanwhile, in the most densely populated areas - 600 inhabitants per km^2 - one finds wooded landscapes, a real human achievement, the people having planted trees everywhere: a phenomenon of intensification and artificialisation of ecosystems leading to the opposite of massive deforestation and a worsening of erosion phenomena. By considering farmers, and farming in general, to be the cause of this looming crisis, it was possible to justify a good many aspects of agricultural policy, including the excessive supervision of producers and the condemning of their practices. So all agronomic research and advisory services were concentrated on improving technical "packages" to be distributed around the countryside, even if they went against the views of producers themselves, which was enough to justify a move to authoritarianism from the regime.

At the same time, since the production curve more or less coincided with the population curve, others advocated Boserup's model, to the extent that, when there was a shortage of reliable statistics, annual production growth was measured simply by adding to the figure for the previous year the same percentage as for population growth! This practice was widespread among advocates of this theory: "overpopulation", both a considerable, and inexhaustible, pool of labour in the countryside, provided justification for "putting peasant farmers to work". This "labour investment" (in Boserup's sense) was made into an equally authoritarian means of mobilising rural people to build roads, drain marshland, *etc*., carrying on the colonial tradition of forced mobilisation of the population.

More recently, this theory of Boserup's has also been accorded neoliberal virtues. Since farmers were able to intensify, it was sufficient for them to be more and more numerous for that intensification to take place: this justified the State and public authorities' withdrawal from any productive role; it was sufficient to make sure market signals reached farmers.

These two theories, despite being systematically opposed, have more in common than it seems, since both take the ratio between population and resources as the starting point for their analysis. So, whether production is considered an independent variable (Malthus) or whether population growth is that independent variable (Boserup), these two theories ultimately coincide in their inability to really explain the crises, to put social relations back at the centre of the phenomena observed, and to attempt to see in what conditions those crises might or might not be overcome.

Although there is still much room for progress, the accumulation of fertility capital, at the centre of the process of development of Burundian agriculture, has today slowed down, hindered in many ways. A massive diversion of biomass to the exclusive benefit of coffee cultivation through the compulsory mulching technique, a shortage of inputs, uncontrolled attacks from parasites, in particular on banana trees and beans, a system of relative prices which makes fertilisers and plant-protection products inaccessible, repeated and massive infringements of free access to resources: all these obstacles make it increasingly difficult to pursue and expand the intensification dynamics under way since the 1950s. The obstacle to the continuation of these processes today should therefore not be sought in the practices of peasant farmers themselves, and the crisis is in no way the result of exceeding a population ceiling imposed by the productive capacity of cropping and livestock systems. It has far more to do with the conditions in which producers are today integrated with market trading and the social relations in which they are involved, which limit the productive capacity of the agrarian system. Just like in ancient Burundian society, the storage and concentration, appropriation and management of carbon are once more at the centre of social relations.

Finally, Burundi's agricultural development has been inward-looking and, despite the development of coffee-growing, has remained above all based on the domestic market, even though that market has remained limited to agricultural produce and highly restricted by the narrowness of urban markets. Protected by 1,500 km of poor roads separating it from the Indian Ocean, Burundi has managed to take control of its participation in international trade and to limit its destructive impact on the food-production sector. Despite very low labour productivity, farming remains alive and the country has for a long time been self-sufficient. The agrarian transformations of the past decades are certainly a remarkable example of endogenous development, based only on local resources. As for coffee, there is no need to revive an old, outdated debate on the competition between food crops and export crops. Coffee was without a doubt the best vehicle for participation in international trade. But it was necessary for Burundi's clear comparative advantage not to have been drastically reduced by the opportunity cost of the biomass required by the compulsory mulching technique for coffee-growing, and the extremely serious indirect effects this had on the national economy.

The origins of biodiversity: genetic resources[1]

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"*We have only two alternatives to choose from: either a number of national, militarized totalitarianisms, having as their root the terror of the atomic bomb and as their consequence the destruction of civilization (or, if the warfare is limited, the perpetuation of militarism); or else one supra-national totalitarianism, called into existence by the social chaos resulting from technological progress*".

Aldous Huxley, *Brave New World* (1931)

"I am often in despair in making the generality of naturalists even comprehend me. Intelligent men who are not naturalists and have not a bigoted idea of the term species, show more clearness of mind"[2]. These few lines written by Charles Darwin to his friend David Ansted show the difficulties encountered by the founder of modern biology. He would no doubt despair if he took part in current debates on biodiversity. In this chapter, we shall try to explain that firstly biodiversity cannot be comprehended as the existence of a set of species; secondly, its protection does not simply involve attempting to save those species that can still be saved and finally that what is at stake in this protection goes far beyond what can be imagined as long as we remain focussed on the notion of species.

Darwin: a dynamic view of biodiversity

In his seminal work, *On the Origin of Species*, written 150 years ago, Darwin presented his theory in the form of a diagram (fig. 1) which he explains in depth and in various chapters in the book. This diagram is read from the bottom to the top and the vertical line represents time. Darwin presents strains which, over time, produce new forms. To facilitate the exposé, time is discretized (*i.e.* discontinued) by horizontal lines. At each time step, new forms appear and many disappear. The horizontal distance between the strains represents their divergence. The fact that competition between close strains is greater than competition between differentiated strains means that the most divergent strains die out less than the others. Due to this, via simple selection of the most distant strains, strains resulting from the same ancestor gradually diverge. Therefore, this diagram presents the mechanism of evolutionary divergence which is the basis of the current view of biodiversity.

1. This text was first published as a chapter in the book *Aux origines de l'environnement* (Gouyon P.H. and Leriche H. dir., Éditions Arthème Fayard, Paris, 2010). Permission granted©Librairie Arthème Fayard, 2010.

2. "I am often in despair in making the generality of naturalists even comprehend me. Intelligent men who are not naturalists and have not a bigoted idea of the term species, show more clearness of mind". Letter dated 27 October 1860 to David Thomas Ansted, a geologist in Addiscombe (Surrey), UK.

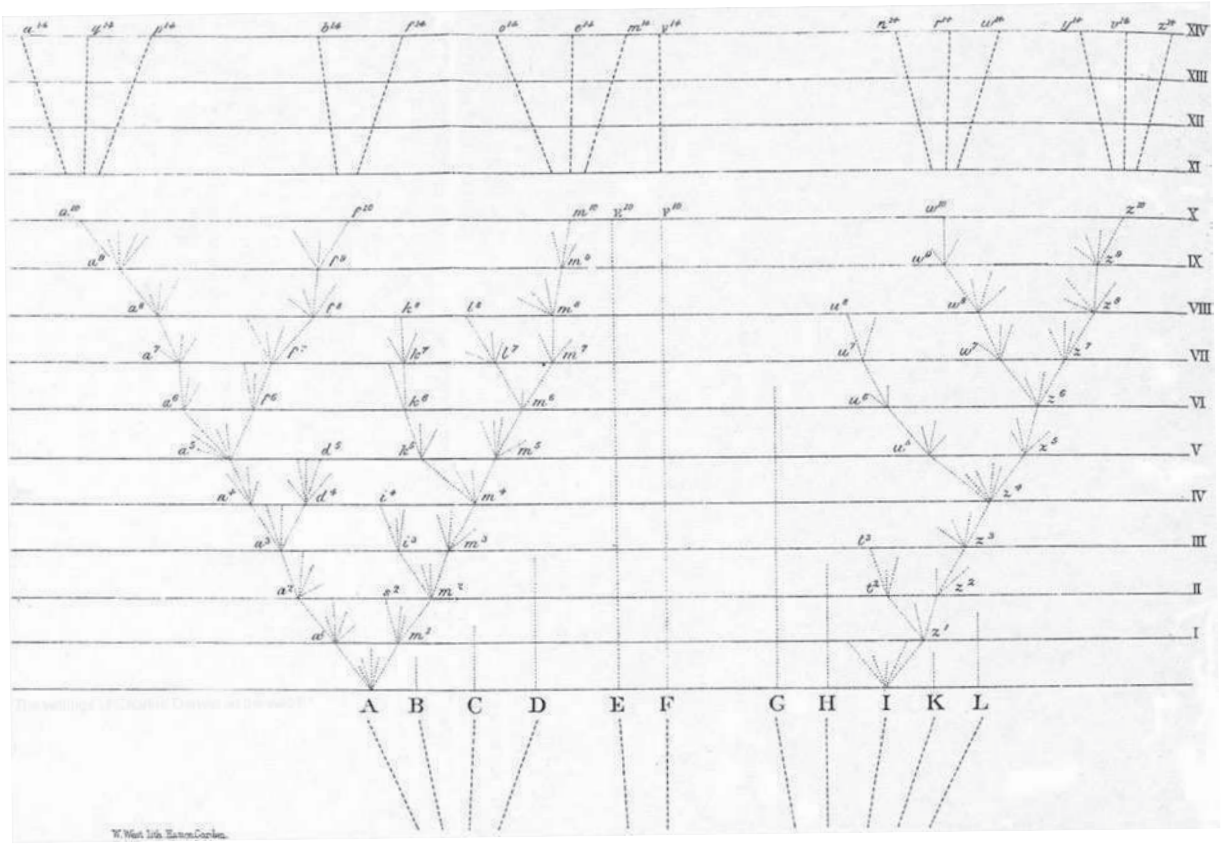


Figure 1. Darwin's diagram (1859).

Darwin makes comments on the left-hand branch of the diagram (the one that starts at A). At the end of the process, it will have produced 3 strains and the future of these strains is drawn above in a less detailed way: "If we suppose the amount of change between each horizontal line in our diagram to be excessively small, these three forms may still be only well-marked varieties; or they may have arrived at the doubtful category of sub-species; but we have only to suppose the steps in the process of modification to be more numerous or greater in amount, to convert these three forms into well-defined species: thus the diagram illustrates the steps by which the small differences distinguishing varieties are increased into the larger differences distinguishing species. By continuing the same process for a greater number of generations (as shown in the diagram in a condensed and simplified manner), we get eight species […]. Thus, as I believe, species are multiplied and genera are formed"[3].

We see that Darwin's view of biodiversity presents two basic characteristics. Firstly, it is dynamic. It comprises a set of hereditary and ecological processes involving the interaction between the different forms and leading to the emergence of new forms and the extinction of some strains. It is the whole emergence/extinction process, based on the ecological interaction processes, which

3. "After ten thousand generations, species (A) is supposed to have produced three forms, a lo, f lo, and m lo, which, from having diverged in character during the successive generations, will have come to differ largely, but perhaps unequally, from each other and from their common parent. If we suppose the amount of change between each horizontal line in our diagram to be excessively small, these three forms may still be only well-marked varieties; or they may have arrived at the doubtful category of sub-species; but we have only to suppose the steps in the process of modification to be more numerous or greater in amount, to convert these three forms into well-defined species: thus the diagram illustrates the steps by which the small differences distinguishing varieties are increased into the larger differences distinguishing species. By continuing the same process for a greater number of generations (as shown in the diagram in a condensed and simplified manner), we get eight species, marked by the letters between a l4 and fn I*, all descended from (A). Thus, as I believe, species are multiplied and genera are formed." *The Origin of Species* (1859), chap. IV, "Natural Selection".

comprises biodiversity. We then see that Darwin draws from the particular level which is a "species" its major status in the process and in the result. Among other things, he writes: "Certainly no clear line of demarcation has as yet been drawn between species and sub-species - that is, the forms which in the opinion of some naturalists come very near to, but do not quite arrive at the rank of species; or, again, between sub-species and well-marked varieties, or between lesser varieties and individual differences. These differences blend into each other in an insensible series"[4].

Therefore, to base the diversity of living organisms on that of species is no longer meaningful within the context of modern biology. In fact, this is a continuation of the perception of nature held in the XVIIIth century. At this period, scientists imagined that the creator had created species and that individuals were the more or less imperfect representatives of them. The great naturalist Carl von Linné wrote: ""All species draw their origin from their strain, in the first place, from the actual hand of the all-powerful creator because, by creating species, the Author of Nature imposed upon its creatures an eternal law of reproduction and multiplication within the limits of their own type." Linné then disqualified variations between individuals within species to establish a distinction between; the true difference, the diversity created by the wise hand of the all-powerful" (the difference between species) andthe variation in the outer shell due to the whim of nature" (the variation within the species).

In this old framework, diversity therefore corresponded to the number of species. It is surprising that, even today, biodiversity is presented in the form of lists of species. Of course, given the massive extinction that we are now facing, it is legitimate to try to save what can be saved (*cf.* The endangered species lists). But to content ourselves with this type of approach and to base our scientific view of biodiversity on such lists comes down to adopting the rigid Linnaean view of creation. In such a framework, it is logical to ask ourselves which of the existing species we should keep, which ones we should get rid of and which ones we do not care about. In fact, that is not the issue.

If we accept the Darwinian view, on the other hand, diversity exists at all scales. All strains contribute to it. Of course, the more the strains are differentiated, the more they weigh on overall diversity. The level of species is not particularly important in this set-up; the upper and lower levels of differentiation must also be considered. According to the current systematic, it is the diversity of the clades that constitutes biodiversity, not necessarily that of the species. But over and above this point, biodiversity should be understood as a dynamic process that fully includes genetic and ecological mechanisms. This point of view can radically change not only what we study and what we seek to protect but also the reasons for doing so.

A dynamic process (demography is an example of this) like the emergence/extinction process (mathematicians refer to the birth-death process) can lead to two sorts of kinetics: either positive kinetics in which perturbations can create fluctuations but which always tend to favour great richness and compensate losses; or negative kinetics in which the system gradually heads towards its ruin because extinctions are structurally higher than emergences (like a population in demographic decline, for example). In the latter case, natural fluctuations can hasten or delay the result, but this result is nevertheless determined.

Today, the whole dynamics of the system seem to be disrupted. Not only is our action on the biosphere hastening the extinction of some species, it seems to have actually changed the dynamic parameters of living systems and led to a decline. Various examples can be given to illustrate this point. If Mediterranean bluefin tuna is becoming extinct, it is no doubt because it is being overfished but also, and above all, because the fish it feeds upon have become too scarce. In another field, we see a staggering reduction in the diversity of varieties cultivated on the scale of the whole planet. What is causing this phenomenon?

4. "Certainly no clear line of demarcation has as yet been drawn between species and sub-species - that is, the forms which in the opinion of some naturalists come very near to, but do not quite arrive at the rank of species; or, again, between sub-species and well-marked varieties, or between lesser varieties and individual differences. These differences blend into each other in an insensible series; and a series impresses the mind with the idea of an actual passage." *The Origin of Species* (1859), chap. II, "Variation under Nature".

One essential aspect of the Darwinian process lies in the fact that all biodiversity draws its origin from genetic diversity within species. That is where everything starts. Therefore, to understand the dynamics of the system, we study the factors that favour or hinder the birth of these differences. In this part, we shall focus on this aspect. It would be tedious to give an exhaustive list of the mechanisms that come into play. However, a detailed study of a very well-known case may help us understand.

First of all, it should be noted that the process highlighted by Darwin in his diagram only operates on two conditions.

First of all, the different entities (families, populations, varieties, sub-species) under consideration must be sufficiently isolated, from an ecological and reproductive point of view, to be able to differentiate themselves. This differentiation will take place through natural selection exerted in different conditions or even under the influence of what geneticists call the "genetic drift". The most common cause of this isolation is no doubt geographical isolation. Geographical isolation protects new strains from competition among themselves - which could lead to one strain eliminating another strain - and from hybridization which would prevent their divergence. It can also expose them to living conditions which develop different aptitudes and thus create an adaptive divergence.

Secondly, the entities under consideration must be sufficiently linked up to avoid the loss of their internal genetic diversity. If each population remained totally isolated from the others for very long periods, each of them would suffer the effects of selection and drift and become too homogeneous to be able to continue evolving.

We see that the production of biodiversity results from a subtle balance between isolation and interconnection. Too much isolation homogenizes each population, too much interchange homogenizes the whole.

The destructive effect of human activity on biodiversity

In this regard, it is easy to analyse the effect of human activity on biodiversity. With the globalisation of exchanges and the isolation of each place due to human occupation, we have broken the dynamics of the system in many places. What with all the seeds, vegetables, pets, insects and seaweed, and not forgetting the bacteria and viruses, we transport billions of living organisms over great distances of the globe, every day. The competition, parasitism and predation thus induced, lead to the disappearance of whole branches of the tree of biodiversity. Numerous marsupials and all the birds of Hawaii have borne the brunt of this. But if we knew what was happening to organisms that we consider less remarkable or that do not appear so different, the list of extinctions would be much more disturbing.

At the same time, we are building roads, motorways, towns, industrial zones and even parks and gardens which just act as obstacles to natural interchange between individuals of numerous populations. This has three major consequences.

Firstly, if each population becomes extinct, there is little chance of it being re-established by individuals from a neighbouring population. This idea has been under study for a few decades via the concept of metapopulation. Most species are made up of a set of populations, each of which may die out, but the whole set manages to avoid extinction thanks to migrants recolonizing territories left vacant by these extinctions. Admittedly, we can offset this problem by building bridges or tunnels to allow animals to cross motorways but this does not solve the problem posed by other infrastructures. All land-use planning projects should include the installation of corridors to connect all "natural" areas.

Secondly, due to various outside causes, like global warming for example, the populations of many species can only survive by moving to another area (northwards in the current situation). However, these movements are prevented not only by infrastructures, but also due to the fact that we designate

a purpose to each zone which is not expected to evolve according to conditions: a forest here, some fields there, a landscape garden over there, *etc.*

Finally, what concerns us most here is that this isolation that is forced upon populations leads to their genetic depletion and makes them unable to evolve.

Globalisation and fragmentation are the two main actions by which we jam the mechanism of biodiversity.

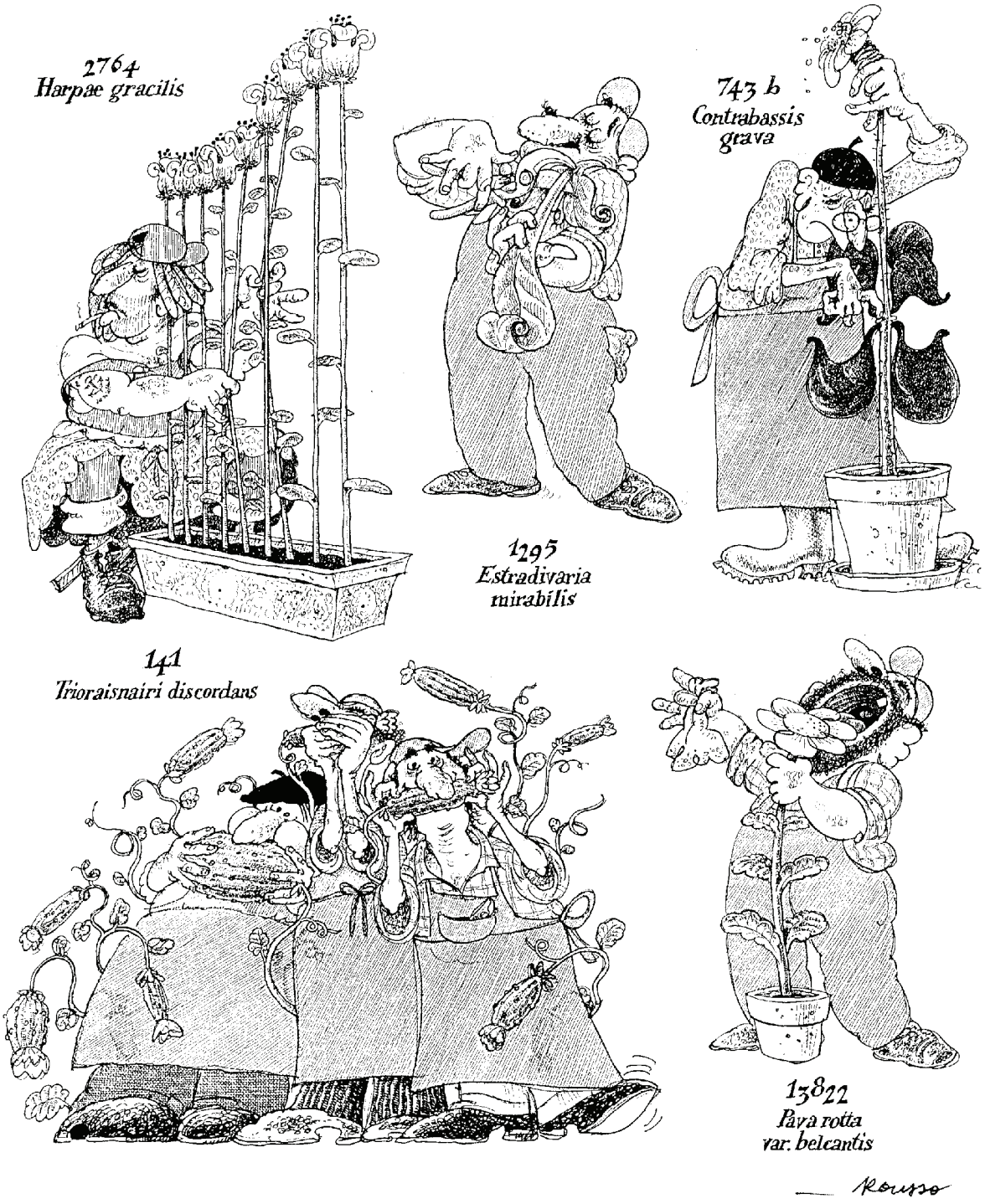
Non-sustainable modern farming

The most striking example of this process is the seeds we use to reproduce the plants which are essential to us because they are our staple foods. What is remarkable is the fact that it was in the XXth century that the issue of protecting what is commonly called our "genetic resources", *i.e.* the part of biodiversity which concerns the species that we grow or breed, was first addressed. In the 1970s, the question became: "how can we curb the erosion of genetic resources". At a period when our western societies thought their technological progress enabled them to better control living organisms and when we were starting to learn how to study and manipulate genomes, the fact that the question was raised in such terms is very surprising. Indeed, it was not a matter of learning how to produce these resources but only how to limit their erosion. To summarise this point, let us focus on plants.

In the last hundred million years or so, evolution has produced a multitude of forms, each of which has great evolutionary potential. For thousands of years, small farmers all over the world have grown some of the plants resulting from this evolutionary process and have increased their diversity even more. The genetic resources thus produced are precious to us. The future selection of these plants relies on these genetic resources. This selection will allow us to increase their potential, meet our needs better and resist different constraints (disease, drought, *etc.*). Yet we farm them without maintaining them. These resources, which were obviously renewable for a long time, have now become exhaustible. On this subject, some specialists talk about a "mining" agriculture or an agriculture which has lost its sustainability, an agriculture which exploits and no longer renews. In this framework, it is no doubt significant that in agronomical terminology small farmers are now called "farm operators".

How have farmers produced all these varieties for thousands of years? By growing species within a framework of isolation and interchange which allows the process of biodiversity to function. The domestication of plants was carried out by maintaining interchanges between cultivated forms and wild forms. Then, when the cultivated forms spread beyond their original territory, each farmer selected his own seeds from the different fields which he farmed. Therefore, each batch of seeds had its own genetic individuality. But the internal diversity of each batch was maintained via a system of exchanges between farmers. The basic process of biodiversity was at work and an enormous diversity was thus created.

In the XIX^{h} century, all that was disrupted by a revolution whose consequences were difficult to foresee. Farmers became specialised: on the one hand, there were those who produced the seeds, the seed growers, and on the other hand, there were those who farmed them. From this time onwards, the plants were only reproduced in the seed growers fields. The crops from all the other fields were all used to produce food, livestock feed, and then industrial products. All of a sudden, none of the biological innovations that appeared in these fields had a future in evolutionary terms. Genetic innovations could only be produced by plant breeders, i.e.a very small part of the farming community who were the only ones responsible for the future of genetic resources. This practice had a positive effect on farm production. Plant breeding enabled great progress to be made in production. Thus, in the agricultural sector, countries like France which had been an importer became an exporter. Everything seemed to be for the best in the best of all possible worlds. But all this relied on the diversity of living forms on which the seed growers' activity was based. Yet, however gifted these



Drawing by Robert Rousso *in le Courrier de l'environnement de l'INRA* nº 44.

seed growers may have been, they could not replace the immense evolutionary territory of all the cultivated fields. They did of course address the problem. Thus, the question of genetic resources was put on the agenda of agronomic issues, research and major international institutions.

An urgent solution was found: gene banks were set up. Refrigerated vaults contain thousands of sachets or recipients, each of which contains seeds of a particular variety of the species conserved. This solution allows us to deal with the emergency. We freeze diversity for a certain time. However, the seeds we place in the cold are not everlasting. They end up losing their germination potential. So we then have to sow them, well isolated from each other, and harvest their descendants which are put back in the fridge. When we do this, we lose some diversity and, in any case, it is not frozen diversity that humanity really needs. It needs living diversity which is capable of evolving with climatic, sanitary and agronomic conditions, *etc.* These banks can only act as a temporary backup solution while we wait for a real, sustainable solution to be found.

At the same time, the number of seed companies has constantly decreased, and with them, the diversity of varieties available. This is due to the fact that the seed companies have been affected by the phenomena of concentration. In France, for example, a seed cooperative - Limagrain - has enjoyed remarkable growth, to such an extent that it has practically eclipsed all the other local companies. On an international level, this movement has been magnified by the fact that agrochemical companies have decided to take over this niche. The phenomena of industrial concentration have reinforced this process further, leading to giants - the most famous one being Monsanto. The consequence, in terms of biodiversity, is that the number of cultivated plant populations actually reproduced is plummeting and this is also the case with the diversity of these plants.

What are the solutions?

There are two types of solution that could be tried to solve this problem. Unfortunately, given the current economic, legal and political situation, they are incompatible.

We can imagine that technology will allow us to offset the loss of these resources. To solve specific problems, we could search for the genes we need in bacteria or other organism (fishes, other plants *etc.*), case by case, and thus we could do without the real living diversity of cultivated plants. Moreover, within this framework, we could content ourselves with freezing this diversity in an enormous underground fridge, like in Svalbard, an island of Norway, where seeds from a large number of current varieties of numerous cultivated plants are stored. As we said, these seeds will die but their genes will remain available for a long time. The operation is presented in the following terms: "Ensuring that the genetic diversity of the world's food crops is preserved for future generations is an important contribution toward the reduction of hunger and poverty in developing countries" but this is based on a fixed view of diversity. Each form is only one part of a fixed whole and the dynamics of the system are not taken into consideration.

The image of "Noah's Ark" is produced by the same type of reasoning. Of course, advocates of this type of approach know full well that the world will change and that cultures will have to evolve, but they set their bets on our technology becoming, in the short term, powerful enough to replace the natural process of the evolution of species, they hope that past diversity is enough to cover the needs of the future and they consider that we do not need to worry ourselves with preserving the process which produced diversity. We see that the "mining" aspect is very present. Diversity will be extracted, just like oil, and when it runs dry, mankind is sure to find "something" to replace it. This is the option taken by biotechnology firms and followed by most States. Within this framework, technological progress must be encouraged. This is done by maximising the profits of innovative companies and, for this purpose, by giving them the ownership of the genetic resources they use and produce. This was the spirit that prevailed when the patent to insert genes into plants, which was first rejected by the United States Patent and Trademark Office and then

by the European Patent Office, was finally accepted, then promoted, thus opening the way to the production of commercial GMO.

On the other hand, we can consider that our fledgling technology has a long way to go before it achieves the selection potential developed by millions of farmers on millions of plots of land throughout the world. In this spirit, it is urgent that we re-initialise the dynamic process of biodiversity. It is not a matter of returning to the Neolithic era. We should develop "participative selection" techniques in which modern-day knowledge of biology, genetics, ecology and agronomy are used to develop farm production in response to mankind's growing needs. Within this framework, each farmer would take part in the selection in a concerted and optimised way and if necessary biotech methods could be used, but the control of genetic resources must no longer be left to a few firms at a global level. Naturally, this would mean that each farmer would own his own seeds and that he would exchange some of them with his neighbours. Consequently, this is incompatible with the previous view based on patents and the appropriation of diversity by just a few firms.

Therefore, the issue is relatively clear, at least with regards the part of biodiversity concerned with cultivated plants. We know the reasons behind the decisions taken. We know the possible solutions. We can hope that technology solves the problems it creates in the future, and instead of sustainable biological systems we can blindly trust our technical abilities of the future. We could also encourage a more humble approach whereby humans, without rejecting technical progress, would attempt to preserve the sustainability of the basic processes which produce living organisms by guiding these processes in the right direction. On this small scale, the whole issue of biodiversity and more generally of the environment is presented. It is not simply a matter of scientific issues but of political choices, and of the way we want our world to evolve. Basically, all the options may prove to be good if they are chosen with full knowledge of the facts; if humans manage to avoid over-estimating the capacity of the things they invent to solve the problems they have engendered.

In all events, if we want to develop a structured view on these issues, we should immediately abandon our old view of diversity based on lists of fixed species and replace it with the dynamic view put forward 150 years ago by Darwin and symbolised in the diagram presented at the beginning of this exposé. Once this has been properly understood, decision-makers will be able to understand what is at stake, and players will be able to act upon the system efficiently.

Cultivating biodiversity[1]

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Since the Neolithic period, humans have transformed a number of plant species at the same time as the environments in which they have cultivated them. This co-evolution of species and cultivation environments has been punctuated by ruptures which historians refer to as agricultural revolutions. The international research movement refered to as "ecological intensification", which has based its work on the intensive use of ecological processes for over 10 years (CIRAD, 2011; Griffon, 2010[2]) represents one of these ruptures, which we will present here, bringing together the viewpoints of a genetics specialist and an agronomist. This rupture consists of reintroducing ecological diversity into agricultural landscapes at the same time as between- and within-species diversity in the crops being cultivated. This is what we mean when we talk about cultivating biodiversity.

This cultivated biodiversity makes it possible to use abiotic resources (light, minerals, water, temperature *etc.*) to the full and to manage interactions between cultivated plants, their pests and their pests' natural enemies in space and time. This is the central idea that we shall develop, supporting the proposition firstly with an overview of the last two agricultural revolutions in Northern Europe, which reveals that an initial ecological intensification was supplanted by farmers making intensive use of external inputs whose limits are only now being appreciated. We then outline research avenues in the new ecological intensification that is now emerging.

The most recent ruptures in the co-evolution of plant breeding and cultivation processes

These ruptures have been described by Mazoyer and Roudart (1997) and Ferault and Le Chatelier (2009).

The first ecological intensification

• *Fallow cultivation systems*

In Northern Europe in the Middle Ages, cereal-based cultivation systems were predominant. Between cultivation cycles were long periods with no cultivated cover, their length varying according to whether the harvest was followed, a little over a year later, by sowing winter cereals or, a little over six months later, by sowing spring cereals. The primary function of these so-called fallow periods was weed control, obtained by a series of tilling operations. Doubtless the fallow period also played a role in interrupting the cycles of pathogens in successive cereal crops, though this is difficult to verify. Depending on whether the long fallow period came round every two or three years, the rotation is described as biennial or triennial.

1. This text was first published in *Le Courrier de l'environnement de l'INRA* n° 60, mai 2010. It is taken from a presentation given to the French Academy of Agriculture on the 13th of October 2010 at a session devoted to biodiversity. A summary of the presentations and discussions that took place at this session can be found in the *Proceedings of the French Academy of Agriculture*, vol. 16, 4, 29-39 or at the website *http://www.academie-agriculture.fr/*

2. Many English-speakers use the concept of "sustainable intensification" with a very similar meaning.

The material lost through harvest was replaced by material transferred by livestock from the areas where they fed: "saltus", or uncultivated pasture, and wooded areas. Stabling improved the quality of this transfer. Based on its direct exploitation of the natural fertility of the "ager" or arable fields and, by transfer, that of the saltus, this mining system exhausted the natural resources.

In the XIVth century, agricultural production regressed. Crop yields fell, and so did the level of organic matter in the soil. To compensate for this degradation and feed a growing population, the ager was extended at the expense of the forests and the saltus, both sources of fertility. The system as a whole was thus not sustainable.

Indeed, natural resources were very poorly used since during the long fallow periods the cultivation system did not use photosynthesis to produce biomass and the repeated tilling promoted the mineralisation of the organic matter in the soil and the leaching away of nitrogen. By making better use of the ecosystems' productive capacity (light energy, nitrogen fixation, crops' pest resistance, *etc*.), continuous cultivation systems, based on using a wide range of crop species, which took the place of fallow systems, constituted a real ecological intensification in the modern sense of the intensive use of ecosystems' natural functions.

• *Continuous cultivation and mixed crop-livestock farming*

Beginning in Flanders, this revolution spread gradually across all of Europe between the sixteenth and nineteenth centuries. Initially, the one-year fallow period was replaced by a forage legume crop (red clover, vetch, sainfoin *etc*.) or a grass (ryegrass), or sometimes a combination of the two, and the short eight-month fallow period by turnips sown as a so-called catch crop. Later, temporary prairies lasting several years, based on alfalfa or white clover and forage grasses, were introduced between the annual crop cycles. The list of cultivated species grew: cabbages and corn in southern regions, potatoes, beetroot, flax and hemp elsewhere. Animals thus found other food on the ager than the little residual forage they had previously gleaned there. Permanent prairies (saltus) were confined to land that was difficult to till due to its nature or its remoteness from habitation.

Thus arose a system of mixed crop-livestock farming in which the cultivation of a wide range of species allowed better use to be made of natural resources. The continuous use of light energy by photosynthesis produced more biomass, which partially returned to the soil and increased its humus content. The weed control that previously justified fallow farming was now provided by the cultivation of a series of varied species: some species sown widely spaced so that weeding could take place; others sown densely to block the weeds' light. The annual or perennial cultivation of leguminous plants fixed the nitrogen from the air, benefiting the whole mixed crop-livestock farming system. The nitrogen fixed by the forage areas was then found in the manure. The succession of different species kept pest populations under control.

From generation to generation, farmers selected their plants, choosing to reproduce the mixtures that were best suited to their farming uses and the cultivation environment. Exchanges between regions renewed intra-species diversity, which would otherwise have been diminished. Plant selection led to diversity.

However, in the quest to produce greater and greater amounts for a steadily growing population, this system eventually reached its limits. Deficiencies in minerals such as phosphorus and soil acidity in the cultivation environment could not be corrected by recycling organic matter locally. From the XVIIIth century, marling and the spreading of ground phosphates from Quercy were practised in France. As for the quantity of nitrogen, a fundamental element in the production of biomass, this was limited by the fixation capacity of micro-organisms in the soil.

The XXth century technical revolution

• *Cultivation systems with intensive use of inputs*

During the XIXth and XXth centuries, the transition from mixed crop-livestock farming to specialist systems making intensive use of inputs took place in stages (Papy, 2008). Thanks to the mineral

theory that emerged in the second half of the XIXth century and the development of transport, physical and chemical deficiencies in agricultural environments could be corrected. The use of lime to correct soil acidity, marling and the correction of phosphorus content became widespread. Once these corrections had been made, the increase in yields was limited by lack of nitrogen. Nitrogen fertilisers were then used to remedy the lack of nitrogen from the air fixed by micro-organisms, even with leguminous crops. But nitrate from Chile (mineral) and guano (organic) were fossil fertilisers that were quickly exhausted.

The increase in biomass production in cultivated ecosystems would no doubt have stopped here, except for a discovery made at the beginning of the XXth century: the synthesis of ammonia from the nitrogen in the air. This made it possible to produce nitrogen fertilisers and enabled biomass production in cultivated ecosystems to be forced further, while modifying the gaseous exchanges between the biosphere and the atmosphere. In the second half of the XXth century, the growing use of nitrogen fertilisation, a radical change in the organisation of plant selection and motorisation together with the development of pesticides, continuing land development (irrigation, drainage) and increased transport drastically changed agricultural production systems. These various techniques of land development, cultivation and plant breeding adapted to each other over time, leading to very consistent production systems. Feeding cultivated plants with large quantities of nitrogen made them vulnerable. Small-grain cereals became more susceptible to lodging; the discovery in Japan of dwarfism genes in a wheat variety known as Norin 10 made it possible to select short-strawed varieties thanks to crosses with American material and then with cultivars at the International Maize and Wheat Improvement Centre (CIMMYT) made by Norman Borlaug. This allowed the best use to be made of higher levels of nitrogen fertilisation (fig. 1; Evans and Fischer, 1999). With these smaller varieties, competition from weeds became more significant, but herbicides solved this problem. Intensive cultivation methods made the crops more susceptible to a variety of pests; pesticides took care of this and removed the need for plant breeders to strive for resistant varieties so that they could devote themselves to improving commercial performance in terms of quantity and technological quality. Motorisation made it possible to act at the right time over large areas, guaranteeing that the various inputs achieved maximum effectiveness.

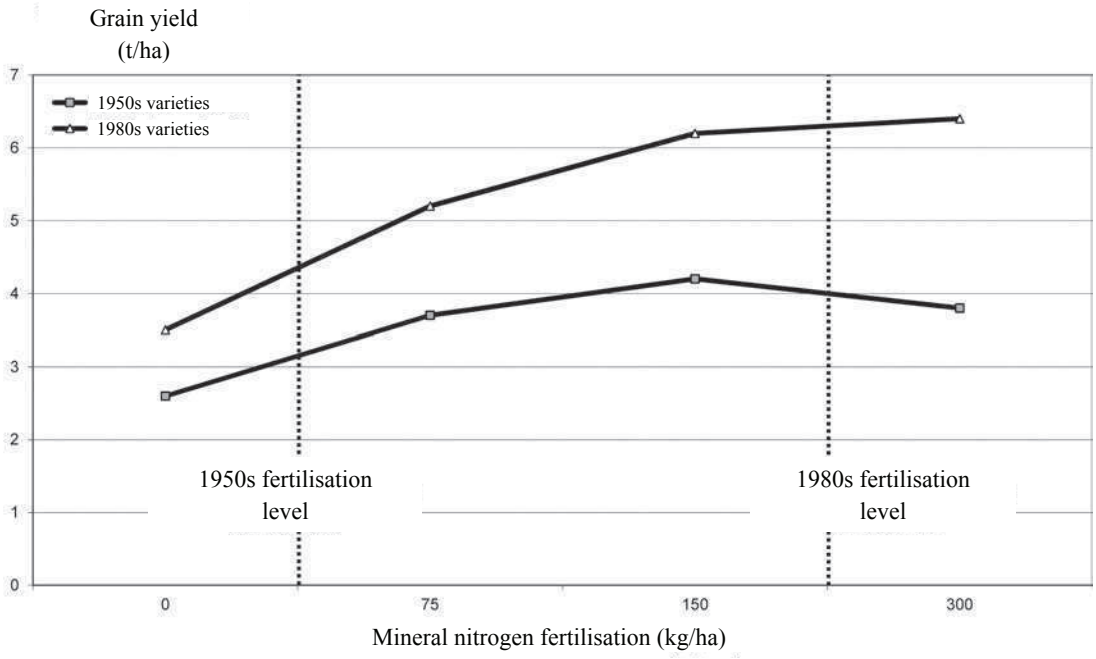

Figure 1. Interaction between cultivars and agronomic practices. Starting in the 1980s, dwarfism genes introduced into wheat varieties give them a better grain/straw ratio and a reduced susceptibility to lodging, leading to better grain production per hectare for equal doses of nitrogen. After Evans and Fischer, 1999.

The large-scale use of inputs removed the need to cultivate diversity between and within species. Arable farming split away from livestock and forage production, as adding manure to arable fields was no longer necessary. The use of pesticides shortened rotations, resulting in certain cases in monoculture. The number of species cultivated in a given place fell. Moreover, within each species, selection restricted the genetic basis of the crop varieties. Populations of cultivated species became more and more homogeneous (pure lines, F1 hybrids or clones depending on the mode of reproduction) in the quest for greater performance in technical processes that were increasingly standardised and tailored to the plant material (Gallais, 2005; Bonneuil *et al.*, 2006). Finally, mechanisation encouraged fields to grow, eliminating hedges, embankments and field borders and thus segregating cultivated spaces from places where wild biodiversity was preserved (Thenail *et al.*, 2009; Papy and Ambroise, forthcoming). The homogenisation of landscapes, varieties and cultivation processes went hand in hand.

Overall, these cultivation systems (like the corresponding livestock systems) were an undoubted success in terms of increased production, which greatly exceeded the food requirements of a growing population. We should also add that the intensification of French agriculture meant that the country's forested area grew by 35 % over the second half of the XXth century, whereas to achieve the same production with 1950s yields a quarter of these forests would have had to disappear. This is a considerable credit to the intensification of arable land in the light of the forests' role in regulating greenhouse gases.

• *The ambiguities of progress*

We are now well aware of the limits of this technical revolution, and there is no need to rehearse them here. At local level, the quality of water and soil has often been degraded and wild biodiversity greatly affected; at global level, it has become clear that intensive agriculture scores poorly for greenhouse gas emissions due to the direct consumption of fossil energy and nitrogen fertilisation; in addition to the energy consumption involved in the production of these fertilisers, they promote atmospheric emissions of nitrous oxide (N_2O), a powerful greenhouse gas. From the 1970s onwards, the fixation of atmospheric nitrogen through human activity, focusing mainly on the production of fertilisers, exceeded the ecosystem's capacity to reduce the oxidised forms of nitrogen compounds to the point that the same quantity of nitrogen was re-emitted into the atmosphere in the ultimate form of N_2 (Galloway and Cowling, 2002).

But apart from the fact that this technical progress was accompanied by damage to our environment, we too often forget that these cultivation and plant selection processes were a regression in relation to the progress of the first agricultural revolution described above. Production and resilience capacities were lost from cultivated ecosystems. The periods between crops when the soil is left bare under-uses the photosynthesis capacity of plant cover at a time when the soil often lacks organic matter; a high level of mineral fertilisation reduces bacterial and mycorrhizal symbioses and consequently the natural capacity to fix nitrogen and the bio-availability of mineral elements; while plants' capacity to capture light energy is taken into account in plant selection, that of the root system to capture mineral elements and water from the soil has often been neglected; in small-grain cereals, selection for dwarfism has been accompanied by a reduction in the root system (Waines and Ehdaie, 2007). Insecticides have often had a directly damaging effect on beneficial species, including pollinators, earthworms and soil arthropods; fungicides are still more toxic; herbicides reduce the number of weed species and, indirectly, useful populations of soil mesofauna (Collectif, 2009). The continuous use of these products, and the reduction in between- and within-species biodiversity (the trend towards monoculture, fixed varieties), induce selection pressures on pest populations, leading to the emergence of pesticide-resistant populations with a serious impact on the plants being cultivated (Deguine *et al.*, 2008). The disappearance of many landscape structures such as field borders, embankments, hedges and ditches have removed habitats for organisms beneficial to the cultivated species.

In short, faced with the challenges of tomorrow, we must now move forward with a synthesis of the last two agricultural revolutions. Reducing inputs and using the productionand resilience capacities

of cultivated ecosystems by reintroducing between- and within-species diversity in crops – these are the avenues that must now be explored.

Research in progress …

… to increase inter-species biodiversity, both cultivated and wild

Inter-species diversification involves organising in time and space the cultivation of several species selected for various production or service functions and maintaining wild species for the service roles they play in the local cultivated ecosystem.

• *Cultivating species diversity*

Doubtless all we are doing is reactivating the role of long rotations in the control of soil parasites and weeds, the effect of diversified cropping systems on airborne diseases and pests and the use of leguminous plants to fix nitrogen from the air *etc.* However, the mechanisms at work are increasingly well understood, including allelopathic[3] biochemical interactions, which seem to have an important role in the relationships between neighbouring species in space (*e.g.* between crops and weeds) or in time (the effect of a previous crop on the species that follows). While many allelopathic effects have been established under controlled conditions, demonstrating their reality in an agricultural situation is more complex (Doré *et al.*, 2004). However, knowledge about these mechanisms in the field is growing. Rotation management is a good example; the role of various brassicas as precursor crops in reducing diseases such as soft rot in peas or take-all disease in cereals thanks to the chemical compounds they release has been studied in detail (Reau *et al.*, 2005). This function of regulating pest populations can also be taken by cultivating other species between two commercial crops.

In the diversification of cultivated species, particular attention must be paid to leguminous plants which, through their symbiosis with rhizobium, save energy in the production of nitrogen fertilisers, reduce gas emissions and enrich the soil with nitrogen. They can provide up to 200-300 kg of nitrogen per hectare in the case of forage or soya (Brunel, 2005), as long as the conditions for the symbiosis to operate are satisfied, which is not the case in slaked or compacted soils. The nitrogen enrichment also helps the other species in the rotation.

Continuous soil cover (very well developed in certain tropical farming systems) is obtained with plants that have no commercial function but serve to prevent erosion, encourage rainwater penetration, trap nitrates, sequester carbon and consequently increase the organic matter and microbial life in the soil. It is often used between rows of vines or fruit trees; in this case, it can be useful to control this cover mechanically or chemically to avoid competition for water in summer (Dupraz, 2005). In arable crops in temperate countries, continuous ground cover is currently little used.

This diversification of cultivated species involves an effort to select plants that have so far been neglected, for not only commercial species but also service species. This gives an idea of the plant breeding challenge which, as Meynard and Jeuffroy (2006) point out, will be measured by the adaptation of the varieties available to the diversity of local demand.

• *Maintaining wild biodiversity*

Maintaining wild biodiversity is also integral to the principles of ecological intensification (Baudry and Papy, 2001; Dupraz, 2005; Deguine *et al.*, 2008; Thenail *et al.*, 2009). Landscape structures such as composite hedges, strips of grass and wild flowers of various widths or just field borders left wild, depending on the case, can serve as a habitat for indigenous beneficial species, an obstacle to run-off and undesirable pollen transfers, a buffer zone… The example of flowered strips that attract adult syrphid flies, whose larvae consume cereal aphids, is a good illustration of the advantage of managing habitats in order to encourage the predators of crop pests and make life difficult for the pests themselves.

3. Allelopathy is the effect a plant has on other plants by the production of chemical compounds released into the environment.

Inter-species biodiversity thus has acknowledged agronomic benefits. The obstacles to its more widespread adoption come from the need to rethink processes both upstream and downstream of the farm in depth and to design methods of coordination between farms within agricultural areas. But what about within-species diversity?

… to increase within-species biodiversity

Before examining the benefits of increasing intra-species diversity, we should note that new cultivation processes imply new varietal ideotypes. This question has been explored in an Academy of Agriculture session in June 2005[4] and in Meynard and Jeuffroy (2006). We can summarise the required characteristics as follows: improved resistance to nitrogen and water stress, generally obtained through better deep development of the root system, whereas, as we have seen, shorter cereal straws have reduced this development; good competitiveness with weeds, and, naturally, resistance to many diseases and predators. But pathogen populations are overcoming resistance more quickly than we can develop new varieties (Gallais, 2005). This is one of the major problems inplant breeding, making it a never-ending activity. For example, this is how the use of Bt transgenic cotton to combat moths has resulted in a race to develop new entomotoxins against resistant individuals due to this phenomenon (Deguine *et al.*, 2008)!

But there are several other avenues of research focusing on intra-species diversity.

• *Varietal diversification in space and time*

A good example of this means of preventing resistance is the American Environmental Protection Agency's requirement that Bt cotton producers maintain refuge zones free of the Bt transgenic cotton. This public-interest measure is designed to dilute any resistance genes in populations subject to selection pressure through genetic mixing (Deguine *et al.*, 2008). It is unfortunately undermined by the short-term interests of producers and the strategies of seed manufacturers[5]. Another example is the CETIOM's establishment in 2003 of a tool to help select varieties following work on the genetic characterisation of resistance to phoma in rapeseed. This provides recommendations for avoiding the proximity in space and time of certain types of resistance (Aubertot *et al.*, 2006).

• *Mixing varieties within a plot*

Here the principle is to combine within a single plot varieties with different resistance genes but the same characteristics determining the crop cycle and ease of harvesting. The main factors in reducing the severity of epidemics through varietal combinations are low density of sensitive plants, the barrier effect of resistant plants and induced resistance (Vallavielle-Pope, 2006; Finckh, 2008). Combinations of genotypes with different abilities to resist disease and adapt to abiotic constraints provide better yield stability than pure crops, and offer product quality that can be equivalent or even superior. Mille *et al.* (2006) have demonstrated this with wheat. Combining varieties is a solution that deserves to be explored further.

• *Mastering a certain intra-variety heterogeneity*

A final avenue is also being explored. As varietal homogenisation was justified by the standardisation of technical processes, it may be wondered whether, as these processes are now less standardised with a view to adapting cultivation processes to the capacities of local ecosystems, it might not be wise to use the evolutionary capacity of the crop populations (Bonneuil *et al.*, 2006). Would this not make it possible for crops to adapt to the evolution in the biotic and abiotic characteristics of an environment, or to different cultivation environments? A network of tests on composite cereal populations has shown rapid differentiation between populations according to cultivation environment in terms of adaptation to both pathogen populations and environmental characteristics, including climate (Paillard

4. Presentation by M.H. Jeuffroy at the 1 June 2005 session.

5. The ambiguities of transgenesis to regulate disease resistance are clear. On one side, government agencies establish rules to limit the spread of a certain type of resistance, and on the other, to maximise the value of their patents, seed manufacturers develop the same resistance genes in several species. This is the opposite of intra-specific diversification; this practice helps pests to overcome resistance.

Figure 2. Wheat diversity © INRA Le Moulon, UMR de Génétique.

et al., 2000 a and b; Goldringer *et al.,* 2006; Rhoné *et al.,* 2008 and 2010; Döring *et al.,* 2010; Wolfe *et al.,* 2008). This justifies a focus on fragmented systems for selecting population varieties as long as the evolution of beneficial characteristics in the required direction and exchanges of seeds between regions to maintain intra-variety diversity are well controlled (Dawson *et al.*, 2010).

Conclusion

The various newly opened avenues of incorporating (or, more accurately, reincorporating) cropping and plant breeding processes into the operation of the surrounding ecosystems will require new relationships between farmers, between farmers and industry, between farmers and seed manufacturers and between farmers and all the other local stakeholders; relationships of coordination and cooperation to make the most of the ecosystems' functional capacities. This is the only obstacle to implementing this ecological intensification (Meynard, 2010). Agronomists will have to be involved in designing the means for a smooth transition. A new relationship between people, and a new relationship between people and natural resources, instead of the relationship of exploiting them and then realising and regretting that they have been exhausted. A whole new economy, in fact!

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IV. Knowledge flows between North and South

"Male-effect": an agro-ecological technique for the management of sheep and goat reproduction and a scientific exchange platform between Tunisia, Mexico and France

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Reproductive management in industrialised countries

Reproductive management in small ruminants, *i.e.* the *a priori* choice of the time and mode of fecundation is interesting for several reasons (Chemineau, Malpaux *et al*. 2007; Chemineau, 2012). First of all it is a tool that provides a major acceleration of the rate of genetic progress, especially using artificial insemination (IA) which allows detecting and then diffusing genes from the best males in the all the flocks. It also authorises the choice of the time of the year for lambing and kidding by the breeder, so that they coincide with food availability and/or more favourable market conditions. Finally, it allows the synchronisation of births, which induces a more restrictive and easier monitoring of lambing and kidding, as well as the constitution of more homogeneous animal batches for food or for sale.

In industrialised countries and in intensive breeding systems, especially in Europe, this management has been the subject of much research after the discovery of the essential roles of steroid hormones, in particular progesterone (P4) and gonadotropic hormones (LH, FSH and eCG or PMSG). P4 allows blocking ovarian cycles followed, after stopping the treatment, by a synchronisation of the cycles of all females, as well as a sensitisation of the central nervous system of animals to facilitate the induction of oestrus (female sexual behaviour) by endogenous oestradiol, at least during the sexual season and with greater difficulty or more rarely during anoestrus or lower spontaneous sexual activity periods. eCG (also called PMSG), extracted from pregnant mare serum, stimulates the ovaries during seasonal sexual rest period, the combination of the two hormones allows the induction of ovulation and heat (oestrus) during this period. Based on these observations, so-called "hormonal" treatments were developed in the 60-70s using P4 analogues (hormones with the same effects) deposited in a vaginal sponge left in place in the females for about twelve days, then removed at the same time as an eCG injection was given to the animals. These treatments, followed by AI at a pre-determined time (so called "blind" without preliminary detection of oestrus) allow obtaining fertilities (kidding and lambing rates)

greater than 60 % in sheep and goats. Several hundred thousands of treatments are used in this manner every year, a great majority of them on dairy breeds (Alpine and Saanen goats, Lacaune sheep).

Hormonal treatment application conditions in developing countries (DP) and development of work on the "male effect"

In spite of numerous trials performed in DP farms, these treatments did not have the same success as in Europe, mainly for two reasons: their cost, difficult to amortise on the sales of products and their difficulty of application on local breeds. For these reasons, scientists in these countries looked fairly rapidly for less expensive means more suitable to their conditions, to manage flock reproduction. Thus the "male effect", introduction of males in a female flock after a period of separation, was studied in the 70s as a collaboration between Tunisia and France in sheep, and then between Mexico and France in goats starting in the 80s.

The male effect was described very early in the scientific publications of the XIXth and XXth century (Girard, 1813; Underwood, 1944; Shelton, 1960). As observed in Cervidae under natural conditions, it allows an effective synchronisation of ovulation and oestrus within days after the re-introduction of an active male within a group of females. This mechanism is particularly interesting, as it only needs the simple moving of animals from one group to another, without using hormones. Considered as the "poor man's synchronisation", it is particularly suited to sheep and goat flocks in DPs which in general belong to small farmers with few financial means.

Several studies were carried out throughout the XXth century on the use of the male effect and its mechanisms, especially by Australian and French teams in sheep (Lindsay, Cognié *et al*., 1975; Signoret, 1976; Martin, Oldham *et al*., 1980; Signoret, 1980; Martin, Scaramuzzi *et al*., 1981; Signoret, Fulkerson *et al*., 1982) and goats (Chemineau, 1983; Chemineau, Poulin *et al*., 1984; Chemineau, 1985; Chemineau, Levy *et al*., 1986; Walkdenbrown, Restall *et al*., 1993a; Walkdenbrown, Restall *et al*., 1993b; Walkdenbrown, Restall *et al*., 1993c).

In sheep, they demonstrated that when the ram effect succeeds, all the females ovulate within 48 hours after the introduction of the male (D0). This first ovulation is followed, in approximately half of the ewes, of a normal duration cycle (16 days) without appearance of oestrus, the rest of the ewes which ovulate at D2 show a short term cycle (6 days), followed by a second ovulation followed a normal duration cycle (16) again without the appearance of oestrus. In both cases, it is after these 16 day cycle that a new ovulation takes place, this time with the presence of an oestrus behaviour (= heat period): the flock then presents two groups, one which is in oestrus at about D18 (2 + 16) and one at D24 (2+6+16). In goats, the mechanism is identical however the duration of the cycle is of 21 days instead of 16 and the heat period is observed at the first and second ovulation following the short cycle, which results in a fairly different distribution of the heat period and the ovulations (figure 1) (Thimonier, Cognié *et al*., 2000; Chemineau, Pellicer-Rubio *et al*., 2006).

At the time, the use of the ram effect in French farms was not of great interest; all the research and development efforts in this sector were concentrated in the improvements to be made to the hormonal treatments. Furthermore, the latter had the support of the veterinary pharmacy companies network and that of AI centres for their development, which was not the case for the ram or buck effect, which in France was restricted to farms producing in organic farming or extensive Mediterranean farming zones (Crau). This technique was looked at with curiosity or even amusement by breeding professionals who at the time would tell us that if we managed *in fine* to develop it with the same fertility results as the hormonal treatments, they would certainly use it as it would avoid the cost of treatment.

This was not the case in Tunisia and in Mexico, where the male effect generated the interest of local scientists for the same reasons that explained the lack of interest in France. Apart from the proof

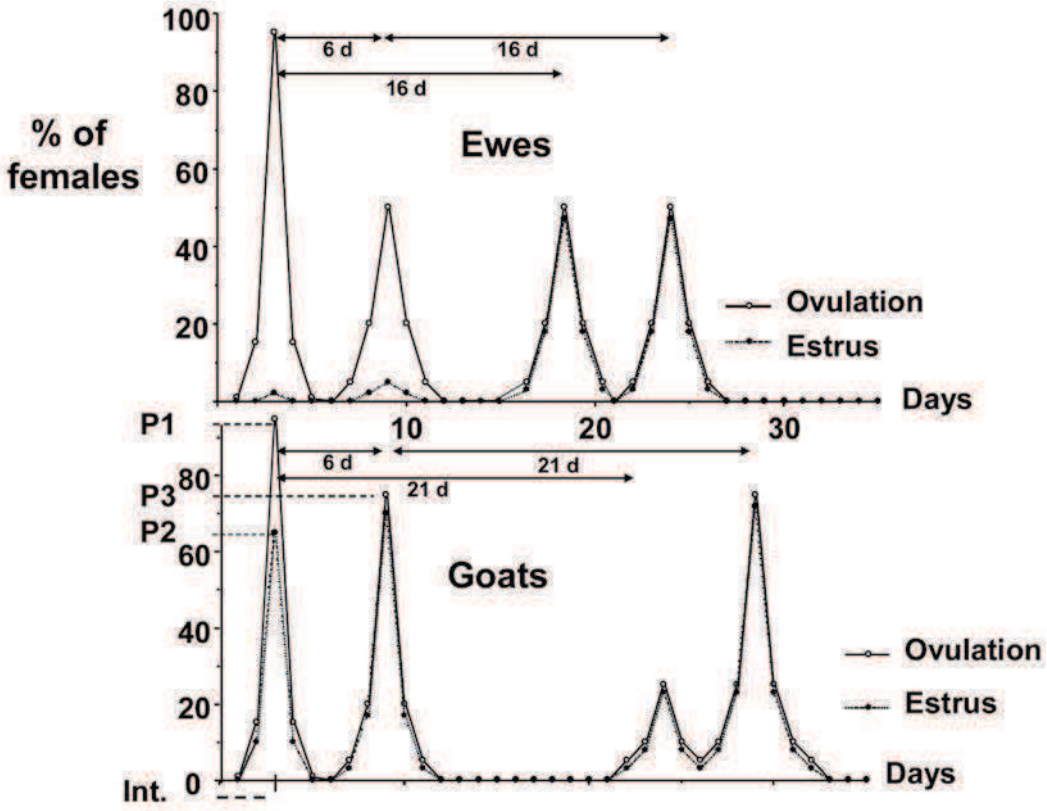


Figure 1. Schematic representation of the ovulatory and oestral response of sheep and goats to the male effect according to Thimonier, Cognié *et al*. (2000) and Chemineau, Pellicer-Rubio *et al*. (2006)). P1, P2, P3 and INT are modulated by the intensity of the anoestrus.

of efficacy and suitability to local Tunisian and Mexican conditions, several points concerning the conditions for use and the ovulatory and oestral response of the females, merited a joint scientific investment.

Development of joint programmes between France and Tunisia, followed by Mexico and France

Under the local breeding conditions in Tunisia, in particular with the fat-tailed Barbary sheep, raised free range and on cereal stubble for the production of lambs, it is important to maximise the fertility in the spring so that the ewes and their lambs may benefit from the food available after the autumnal Mediterranean rainy season. The work carried out with the INRAT and INAT of Tunis, focused on several important factors for the success of the ram effect, on the ovulation and oestrus response of the ewes to the introduction of the ram, as well as the interactions between these two factors.

It was thus possible to specify from which stage after lambing, the ram effect was effective and what were the food availability conditions at the time of lambing that led to a body condition suitable for the response to this stimulation (Khaldi, 1984; Lassoued, 1989; Abdennebi and Khaldi, 1995; Naziha, Bocquier *et al*., 2004). Several very original results were produced in this framework by Tunisian scientists. The first concerned the effects of the body condition of the ewes at the time of lambing in the autumn, which modulates the percentage of short cycles in response to the ram effect in the spring: when the body condition is low in November, the percentage of short cycles is high in May (Khaldi, 1984; Abdennebi and Khaldi, 1995; Lassoued, 1998). This fairly unexpected effect is

interesting both on a scientific level and on an applied level, for the management of the flocks. The second concerns the use of a temporary nutritious feeding prior to joining for reproduction (referred to as flushing) which as may be expected increases the rate of ovulation during the first ovulation induced by the male, but which is incapable of reducing the percentage of short cycles that follow this initial ovulation and which are a problem if AI is desired.

Many studies have been performed in Tunisia to try to better understand the physiological determinism of these short cycles that follow the first induced ovulation. Uterine prostaglandins are involved in the control of early luteolysis (disappearance of the corpus luteus during the short cycle) which takes place 6 days after the introduction of the male (Lassoued and Khaldi, 1989; Lassoued, Khaldi *et al*., 1997). The presence of the male induces an initial ovulation within 48 hours, followed by a burst of growth of the ovarian follicles at about D3-D4 accompanied by the secretion of oestradiol, which is itself very important to stimulate the secretion of the uterine prostaglandins and induce the resulting short cycle. Therefore, the mechanisms that initiate the early secretion of the luteolytic hormone between D4 and D5 by the uterus, is caused by the oestradiol secreted by the initial burst of ovarian follicles on days 3 - 4 of the luteal phase induced by the male effect. This result contributes to the explanation of the constancy in the duration of the induced short cycles. It has also been demonstrated in sheep that progesterone applied prior to the introduction of the ram, known in other studies to suppress induced short cycles, acts at the uterine level, probably to inhibit this prostaglandin secretion and prevent early luteolysis (Lassoued, 1998).

Simultaneously with these studies, the ram effect was implemented more systematically in large cooperative or State flocks in different points in Tunisia, which led to a significant improvement in the numerical productivity of these flocks.

A similar process was undertaken with goats in Mexico, where the male effect turned out to be of interest, in these sub-tropical latitudes where the photoperiodic variations are smaller in amplitude. In the north of Mexico, in the Comarca Lagunera, local Criolla goats, at the base of a “mixed” breeding system, product milk and kids to provide an income to farmers with very low means. The flocks are free range during the day. The use of the buck effect in the spring, seasonal ovarian inactivity period in this goat population, allowed shifting the kidding to a period more favourable for the survival of the kids and the sale of the milk. After a very careful description of the reproductive characteristics of the local populations, especially with respect to their seasonal sexual activity which was unknown until then, the work consisted in understanding the factors that determine this seasonality (Delgadillo, Flores *et al*., 1998; Delgadillo, Canedo *et al*., 1999). Contrary to what had been expected, it was not the high variation in available feed but the photoperiodic variations which induce a fairly long sexual rest period in the female between February and August and in males between January and June (Delgadillo, Cortez *et al*., 2004). This result as well as the low response rates of goats to a buck effect carried out with males in sexual rest, led the Mexican team to test the response of females to the introduction of males which were turned sexually active by simple photoperiodic treatments, applicable and applied in open buildings or in temporary outdoor pens (Flores, Veliz *et al*., 2000; Delgadillo, Carrillo *et al*., 2001; Delgadillo, Flores *et al*., 2002).

This photoperiodic treatment of the bucks allows a spectacular increase in the response rate of the females and leads to high fertility in the spring, which was the effect sought by the farmers. The robustness of this process was demonstrated, as well as the use conditions specified, in particular with respect to the sexual stimuli of the buck which are responsible for the female response (odour, contact, behaviour, vocalisations, eyesight). The implementation under the practice conditions was specified (Fitz-Rodriguez, Hernandez-Bustamante *et al*., 2007; Delgadillo, 2011). Sexually active bucks can be introduced in flocks maintained under difficult free range conditions and may be used only over a 24 hour period (for example at night, in the goat shed) with fertility results identical to those of goats maintained in continuous presence with the males (Rivas-Munoz, Fitz-Rodriguez *et al*., 2007). The importance of the intensity of the sexual activity of the buck in the quality of the response of the does and in the success of the treatment have been revealed (Delgadillo, Flores *et al*., 2006; Delgadillo, Gelez *et al*., 2009).

This led to the development of a simple, inexpensive and effective technique to allow breeders to strongly increase the fertility of their goats in the off-season (Delgadillo, 2011).

Essential elements for the success of collaborations between the different laboratories in Tunisia, Mexico and France

In our opinion, the collaborations were based on four essential elements: scientific curiosity and solidity, reciprocal trust, time and means.

It was first of all the scientific curiosity which seems to have guided the work carried out throughout these years. An annual meeting was held between the participants in one of the collaborating countries to be able to discuss the work hypothesis to be tested in the experiments for the following year. We all have souvenirs of pleasant and joyful scientific meetings for which freedom of thinking and imagination were the principal motors to the discussion. This freedom was always associated with a strong experimental rigour with the objective of obtaining the means to statistically proof the expected results, as well as the objective of later publishing the results in good international scientific journals.

Afterwards, the reciprocal trust between the different partners constituted one of the bases of these collaborations. This reciprocal test allowed collaborating without preconceived ideas, without a hegemonic will, only concerned by simultaneous scientific progression and providing concrete and inexpensive solutions to local problems. Trust was also involved in the harmonisation and complementarity between the experiments performed in the different sites, which we always wanted to be strong, as well as in the writing of the scientific articles issued from these collaborations.

Time was also an important factor for this type of collaboration which organises annual experiments and require several years to be able to securely demonstrate or eliminate the hypotheses put forward. In the two cases mentioned, this collaboration was established over more than twenty years.

Finally, last point but not less important on a practical level, these collaborations required major financial means, first to finance in Tunisia, Mexico and France the salaries of the researchers, engineers and technicians involved in the work, as well as the expenses related to the experiments performed, the measurements carried out on the animals and travel between the different countries. These collaborations were supported by different means, in particular by the respective institutions of the participants, bilateral cooperation programmes and more recently by national financing agencies. The results obtained and applied in the three countries involved are a "public good", that can be use for free by farmers in these countries.

Reciprocal interests of the programmes carried out in Tunisia, Mexico and France

As indicated above, at the time the collaborations started, the interest for such techniques in industrialised countries was fairly low and concerned more Tunisia and Mexico than France. With time, we have witnessed a progressive change of the situation. The environmental concerns associated with the "Grenelle environmental initiative" in France, the need to develop more sustainable and less invasive techniques that do not use exogenous steroids and that can provide a better image of breeding farms, reinforced the interest in these methods.

The large scientific and technical capital accumulated in the framework of these collaborations over more than twenty years constitutes a solid base to effectively develop sustainable techniques for reproduction management in French and European goat and sheep flocks. Thus, the importance of the corporal conditions at about lambing for the ram effect response, the role of the sexual activity of the buck in the quality of the female response, the elucidation of part of the underlying physiological mechanisms of the complex oestral and ovarian response which follows the first

induced ovulation, are part of the elements that allow the programmes currently being carried out in France and in Europe to progress faster and more effectively (Pellicer-Rubio, Lebœuf *et al*., 2008; Chanvallon, Sagot *et al*., 2011; Fatet, Pellicer-Rubio *et al*., 2011).

In a sort of "boomerang" effect fairly unexpected twenty years ago, the work carried out in collaboration with Tunisia and Mexico, have come back to use not only allowing a likely acceleration of the development of these alternative techniques, but also a substantial saving on the costs generated by this research.

For the Tunisian and Mexican teams, apart from the use of the results on a local level in order to improve the efficacy of breeding systems based on local breeds and on sustainable and inexpensive techniques, these collaborations resulted in joint publications in peer-reviewed international journals, providing these laboratories with an international reputation. In the case of Mexico, the strong publication activity allowed a national and international recognition and the creation of an international research centre in caprine reproduction (CIRCA) which is currently one of the most respected at the world level in its sector. The quality applied to these studies performed also allowed the creation of a new focus point at the level of the third university cycle teaching in which the CIRCA participates and a greater national recognition of this teaching by the governing bodies.

Joint publications by the laboratories

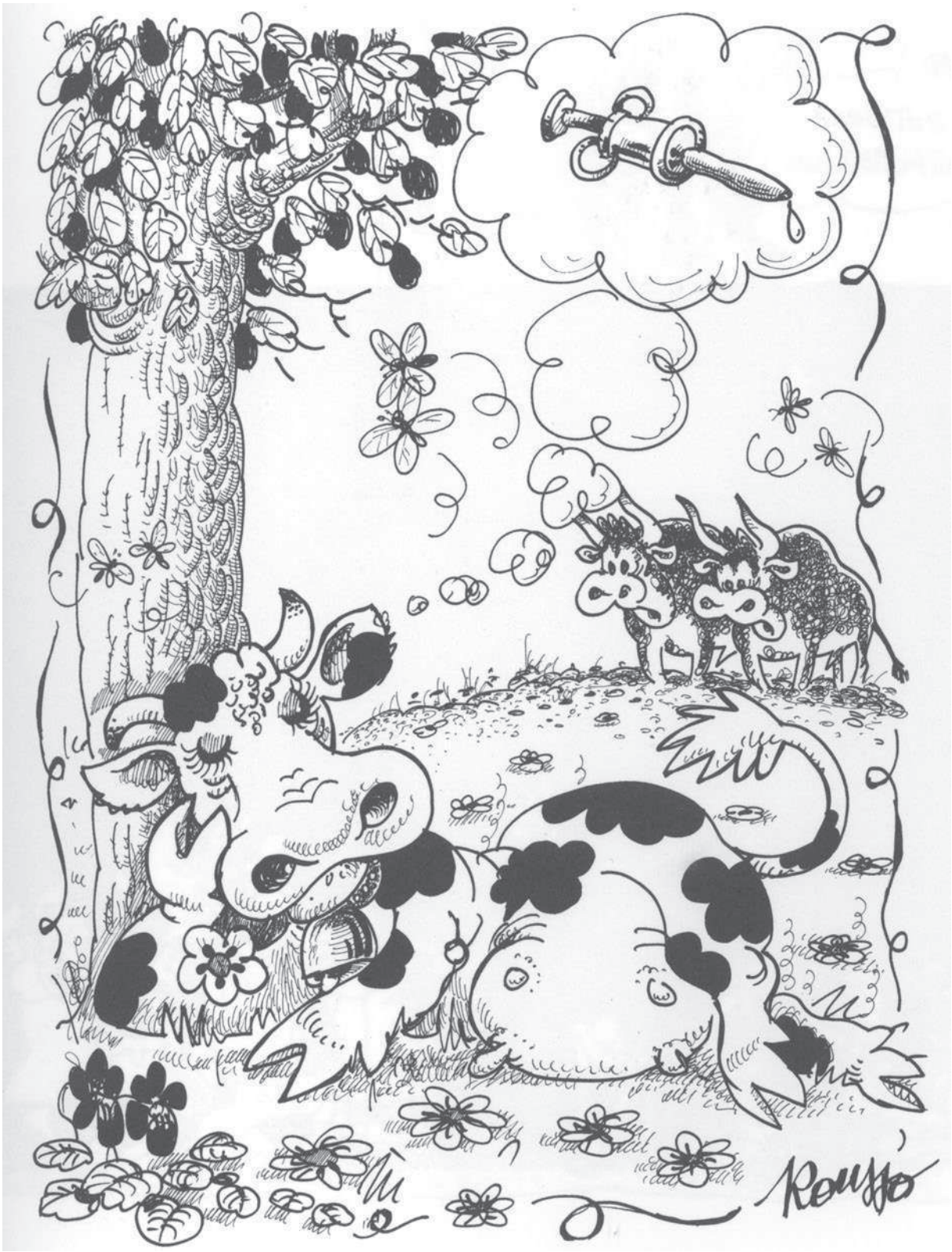
As indicated above, one of the objectives of these collaborations was to have joint publications in peer-reviewed international journals from the scientific and technical results issued from the joint work. At each annual meeting of the partners and for each experiment carried out, an in-depth discussion took place concerning the publication journal, the content of the article in terms of objectives and scientific reasoning, as well as the presence and order of the name of the authors.

There are several reasons to explain this desire to publish the results obtained at an international level. Firstly, so that scientific community could benefit from the results acquired on these alternative reproduction management techniques, especially researchers from other countries in which low-income goat and sheep breeding is present. We notice that these publications are now also useful for researchers in industrialised countries who wish to develop such techniques. Secondly, we wanted to prove *a priori* and/or *a posteriori*, to the financing organisations that the work performed had a good international level and deserved having been or being supported. Finally, it was important to bring out in the two countries considered, a group of scientists capable of acting both locally to develop effective reproduction management techniques, intervene in the international scientific community and being our interlocutors for the future of the programme. It is interesting to observe that some of them are now invited in France to national meetings to present their results.

Conclusion

Using these two examples of collaborations between Tunisia and France and Mexico and France, we wanted to show that the biological questions considered about thirty years ago and which aimed at developing inexpensive reproduction management techniques for small ruminants in low income "Southern" farms, are finally the same being currently asked in French and European farms wishing to implement alternative techniques to exogenous hormones.

The work carried out in this framework gave results which are useful today in high-income "Northern" farms, which is not a result that was initially expected. This seems to illustrate to us the need to establish relationships between researchers based on trust, reciprocity and duration, at the same time as a scientific excellence requirement.



Drawing by Robert Rousso in *le Courrier de l'environnement de l'INRA* nº 24.

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The development of livestock farming in Morocco: relative successes and food dependency[1]

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Located in the Western fringes of North Africa, Morocco stretches from the Atlantic Ocean to the Sahara Desert. It presents a wide variety of agricultural ecosystems: rain fed Atlantic plains mainly cultivated with cereals, large scale irrigated schemes in semi arid regions, mountainous zones, oasis and desert areas. One of the main characteristics of the country is its arid to semi arid climate in most of its parts, which constitutes an acute challenge to secure food supply. Moreover, the country is a net importer of food, mainly cereal grains, as imports have reached in year 2009, according to official data, more than 2.3 million tons of wheat, representing a gross expense of about 415 million US $ (Office of Currency Change, 2010). The wide diversity of agro ecosystems in Morocco has allowed the emergence of contrasted breeds of ruminants, adapted to these systems. This animal wealth (mainly cattle, goats and sheep, with respectively 2.7, 5.2 and 17.6 million heads in 2009) has traditionally assumed various vital roles, from the control of rangeland territories and their resources, to the supply of animal proteins and even religious functions. In fact, as a human society which used to have a strong tribal structure, livestock production has always represented a privileged way of using natural resources and creating income (Miège, 1961). During the colonisation era (from 1912 till 1956), livestock products (mainly meat, poultry products but also wool and leather) were intensively coveted by ruling powers (Spain in the North and the South, France in the centre of the country), as they were considered of high economic value, at a time where Europe was at war. In fact, Morocco was famous for its leather goods and handicraft, and its mutton from extensive pastoral systems (Vaysse, 1952). Northern parts of Morocco were also known to be the cradle of the Merino sheep breed (locally known as Béni Hsen), which was originally exported by Berbers ruling in Andalucia (Southern Spain), during the Merinids' dynasty, who were in power in Morocco from 1269 to 1465. The Merino breed then became popular in Europe and spread worldwide, mainly to Australia, where it has evolved to become a major global producer of high quality wool (Flamant, 2002). The original extensive livestock production systems proved to be adapted to their numerous functions, and farmers adopted sound practices to deal with hazardous conditions. In fact, in the whole Maghreb region (Algeria, Morocco and Tunisia), in periods of intense drought or during political unrest, breeders used to conserve only limited numbers of reproductive females, as they can allow them to reconstitute the herd whenever the climatic and/or socio political situation gets normal again (Tillon, 2000). These strategies have proved to be adapted in a context of a limited demographic expansion. However, sometimes in periods of intense troubles, such strategies would not be sufficient to prevent enormous rates of mortality in herds and animal products' shortage for human consumption (Lakrakeze, 1993). At the end of the colonial episode, in 1956, it became obvious that the rapid expansion of the human population coupled to its changing standards of living, linked to the emerging of important urban poles, would constitute a real challenge

1. This text has been published in french in *Le Courrier de l'environnement de l'INRA* n° 60, may 2011, 91-101.

for the public authorities to secure the supply of animal proteins. Some adapted policies devoted to livestock production had to be designed and implemented. In this paper, the focus will be on the consequences of these livestock policies on the supply of animal products in Morocco and their recent effects on traditional extensive cattle, goat and sheep systems. First, a detailed analysis of the evolution of the demand of animal products will be presented. Then, the impacts of the livestock policies adopted will be assessed and their consequences on extensive systems will be precised. As a conclusion, a reflexion on the future of livestock farming to enhance food security and to achieve a harmonious decentralised development of the country will be drawn.

Recent demographic changes in Morocco and their impacts on animal products' demand

Morocco has experienced marked demographic changes during the XXth century. In fact, from 1956 to 2008, the Moroccan population has more than doubled (15.3 to 34.3 million inhabitants). During the same period, the urbanisation rate has increased at a steady pace from 27.8 to 55.1 % (Catin *et al*., 2007). The increase of the urban population was mainly due to rural exodus, and it created a situation where the urban system is relatively unbalanced as it is dominated by the agglomeration of Casablanca (almost 3.5 million inhabitants, more than 10 % of the country's overall population). These rapid demographic changes have implied the emergence of important social needs: food, schools for youngsters, job opportunities, *etc*. The rapid urbanisation trend has also brought a change in the traditional way of living, and its substitution by westernised consumption habits. For instance, the structure of the society which was linked to tribes mainly living on rain fed cereal crops coupled to extensive sheep production in range lands has shifted to more individualistic behaviours within big cities. Therefore, even eating habits have notably changed from meals which were taken collectively at home, to individual meals (fast food) consumed outside. These evolutions have had marked consequences on the demand of food. They have implied a progressive emergence of metabolic diseases such as diabetes and obesity, as they have been associated to a more sedentary way of life (Rguibi and Belahsen, 2007). Particularly, mutton which used to be the most popular kind of meat consumed is rapidly loosing ground to poultry and dairy products, at a time where beef consumption also stagnates (Sarter, 2006). In particular, mutton is getting considered as a source of health troubles, as many consumers consider that it has a high content of cholesterol. In addition, mutton and beef prices, more than the double of broiler meat, penalise red meat consumption. Finally, mutton does not seem to be enough suited to fast food preparations like sandwiches and pizzas. Mutton therefore seems to have gained the status of a more festal meat, which consumption is more associated to social and religious rites and festivities like baptisms, returns of pilgrims from Mecca, and above all, the religious occasion of Ibrahim's sacrifice – El Aïd El Adha, which is locally named El Aïd El Kébir, to be translated as "the most important religious ceremony" – (Sraïri, 2011). The latter imposes to each adult Muslim, once a year, to sacrifice a well conformed lamb. Given the realities of its average income combined to the cultural characteristics of the Moroccan population, levels of animal products' consumption remain however weak: less than 50 kg of dairy products, 20 kg of meat (5 of mutton and 5 of beef and 10 of poultry), with marked individuals variations. Therefore, significant increases of these levels of consumption might be expected, whenever the households' incomes would improve.

Livestock policies and their effects on the supply of animal products

The sudden emergence of intensive poultry

The first evident measure to increase animal products' supply in Morocco was the launching of private poultry farms, from the beginning of 1960's. These facilities settled near to the main port *i.e.* Casablanca, as the country does not produce cereal grains (maize) and legume crops (soy bean)

which are necessary for this kind of business. Moroccan imports of maize grain went on increasing rapidly, as they have reached in 2008 more than 1.9 million tons from 0.1 million tons in 1981 (Office of Currency Trade, 2009). This represented in year 2008 a gross expense of more than 343 million US $. Today, poultry products from modern facilities represent more than 50 % of the total meat consumed by Moroccans and 90 % of eggs. In a country where pork consumption is more than marginal due to religious considerations, the poultry sector has been under the spotlight to ensure cheap animal proteins' availability to citizens. There has been a similar trend in the increase in the output of poultry products in Morocco as what has been reported by Speedy (2003) worldwide, in comparison to the ruminants' sector. The modern poultry sector has therefore experienced a sustained growth, for eggs (from 201 to 2,700 million units from 1980 to 2008) and broiler meat (70,000 to 440,000 tons in the same period) (FISA, 2009). Hence poultry products represent a convenient source of proteins to wide social classes, as their prices and availability do not suffer from climate variations. However, the poultry sector in Morocco presents several weaknesses, as it is highly dependant on imported feedstuffs and genes. It is also highly vulnerable to heat stresses which commonly affect the country during summer. In fact, in such periods locally known as "*chergui*", even night temperatures may reach some 50°C during 2 to 3 consecutive days, which means high mortality rates and decreased animal performances. Finally, the avian influenza crisis (2006) has had tremendous effects on the sector, as it has ruined many farmers. Last but not least, the vast majority of poultry facilities settled initially in areas near big cities close to Casablanca, as they depended on imported inputs. Today, many of these facilities have become engulfed into the urban space, which creates many problems related to excreta and dead bodies' management.

The difficulties to implement modern dairying in smallholder farms

Another significant step to increase the availability of animal products in Morocco in order to satisfy growing needs consisted in the adoption of a national dairy strategy, namely a "Dairy Plan". This was officially launched by mid 1970s and it relied on several measures: *i*) the constitution of a dairy nucleus by the imports of heifers and the encouragement of crossbreeding between local breeds (not selected for intensive milk production) and specialised dairy breeds (Holstein, Montbéliarde, Fleckvieh, *etc*.), through artificial insemination, *ii*) the development of fodder crops (mainly alfalfa, maize, berseem, *etc*.) in large scale irrigation schemes to secure the sustainability of the dairy activity and to avoid its failure in a context of acute water stress, *iii*) the promotion of a policy of milk collection to allow smallholder farms with less than 5 cattle (which represent more than 80 % of total herds) to sell their output regularly, and *iv*) the implementation of heavy taxes on imported dairy products, to ensure the competitiveness of local products. This strategy has proved to be successful to boost milk production, which, from 1970 to nowadays, has been steadily increasing (figure 1).

However, climatic hazards have affected it, particularly during drought periods of 1981-1982-1983 and 1993-1994-1995. Moreover, from the beginning of the 1980s, structural adjustment programs affected the State intervention in the dairy supply chain, which meant a rapid collapse of all kind of incentives to dairy producers. This has rapidly prompted an increase in inputs' prices (feed, but also services like artificial insemination, which has become in the hands of private operators), at a time where farm gate milk price was stagnating. All together, these evolutions have implied that the dairy activity has currently to manage growing difficulties, from soaring prices of strategic feed (above all, imported cereal grains and proteaginous meals), to water stress. Therefore, cattle farmers' average gross margin from that activity remains generally low (less than 200 US $ per cow per year, including calf crop sales) and is very variable, from positive results to deficits (Sraïri *et al*., 2009a). The decisive factors which affect the average milk yield per cow in a herd are primarily sufficient feed availability (moreover fodder) and secondly its use within balanced dietary rations, as farmers often ignore the basic principles of ruminants' feeding. In addition, in a country where water availability is quite low (less than 800 cubic meters per capita per year), the agricultural sector (more than 85 % of total water volumes' uses) will have in the near future enormous challenges to deal with in order to manage that resource efficiently (Blinda et Thivent, 2009). With regards to the dairy activity, water productivity through cattle rearing is crucial, as

more than 60 % of total milk volumes originate from the large scale irrigated schemes which represent less than 15 % of the country's total arable land. The study of water productivity through herds' performances constitutes a complex task, as it necessitates to analyse a series of functions of production: *i*) from water volumes entering fodder plots, to *ii*) fodder quantities produced within these plots and eventually the amounts of "virtual water" (Allan, 1999), represented by the extra farm feed resources added to fodder for cattle, and finally to *iii*) cattle products, which are in the case of the vast majority of smallholder farms in Morocco, both milk and live weight gain simultaneously, as herds are generally of dual purpose (Le Gal *et al*., 2009). A series of on farm research was conducted recently in a large scale irrigation scheme in Morocco to try to assess water productivity through cattle farming and the way it may be improved. Results showed that almost 1.8 cubic meters of water were necessary to get a single kg of milk, whereas 16.5 cubic meters of water were used to produce one kg of beef (Sraïri *et al*., 2009b). These values were quite close to the international standards of water footprint to get milk and meat (Chapagain and Hoekstra, 2004), but in the specific case of Morocco they reveal that more attention has to be paid to that issue, as the water used is often from groundwater sources, which may be depleted if no regulation mechanisms are adopted to ensure their sustainability (Hammani *et al*., 2009). The analysis of the series of production functions to convert water to cattle products revealed that wide margins of improvement existed within farms, to increase water productivity. These interventions may be targeted to irrigation systems (from gravity systems to drip irrigation), fodder biomass yield (by generalising sound farming practices, from soil fertility to pests' management) and the species of fodder (for instance, the replacement of alfalfa which is a perennial crop by maize which has only a 4 months cycle) and finally animal feeding (the systematic use of balanced and sufficient dietary rations). All these measures require however a close follow-up of farms, and adapted technology transfers tools to farmers, if they are to adopt definitely these changes. During the course of this research, a program tried to test the effects of a close monitoring of five herds' feeding practices, and it clearly demonstrated that the average milk yield per cow could be significantly increased, just by correct advice to farmers: matching dietary rations' nutrients supply with lactating cows' potential production energetic and protein needs (Sraïri *et al*., 2011).

Another significant challenge which already affects the dairy sector in Morocco consists in milk quality management. In a context where smallholder farms still represent the main contributors to the output, their daily production has to transit by co-operative collecting centres, to decrease logistic costs before being processed by dairy plants. This two stage chain creates obvious limitations to assess quality and to implement traceability (Sraïri *et al*., 2009c). In such a system, it is quite impossible to reward individually farmers with good quality milk and to penalise those who have milk

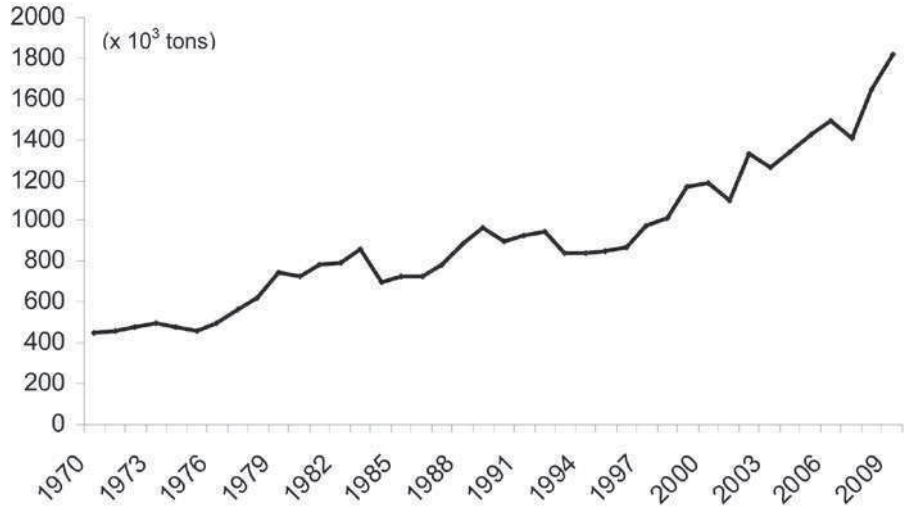

Figure 1. Milk output in Morocco from 1970 to 2009.

with a high contamination by micro organisms and/or with a low protein or fat content. Simply, because the costs of these analyses would be, for the vast majority of the batches that are delivered daily, higher than their real economic value, as many farmers sometimes bring less than ten litres per day to the collection centres. Therefore, milk quality and its fair payment also constitutes a hot topic for the dairy chain, and because it is still not rewarded on scientific bases, it creates a source of tension between dairy farmers and some dairy processors.

All together, it appears that modern dairying in Morocco has many important challenges to deal with in the near future, particularly at a time where the country is negotiating a free trade agreement with the European Union. As the pressure of water stress is getting tense, and because of the structural organisation of the chain dominated by numerous smallholder farms, targeted measures will be needed to ensure competitiveness. This will require further measures to upgrade the whole dairy chain, from its human resources to a fair value distribution within the chain for the benefits of all operators.

Changes in the traditional livestock systems from marginal areas

Apart from modern poultry and intensive dairy cattle, animal husbandry in Morocco has always been interested in extensive livestock production. There is a very old tradition of camels, sheep and goats breeding within wide range lands, whereas cattle are more associated to cultivated areas. Because of the numerous agro ecosystems existing in the country, there are many breeds of these species that have naturally been selected. Dealing with cattle, three main breeds (Oulmés-Zaër, Atlas Brown, Tidili) have been identified and they are all highly adapted to harsh environment (feed restriction due to summer drought) through physiological abilities (recycling of endogenous nitrogen, limited live weight which implies reduced energy needs, *etc*.), but their potential milk yield and their growth traits are limited. Therefore, their main goal of production is calf crop, as farmers aim at getting an average of one calf per cow. This is hardly achieved, because of common reproduction failures associated to frequent nutritional imbalances in herds, particularly during summer, or in periods of drought (Haddada *et al*., 2003).

Morocco is also known for its sheep production, as it currently represents the twelfth flock in the world, with more than 17.5 million heads That has allowed a production of almost 120,400 metric tons of mutton in year 2008, representing the seventh agricultural product of the country by value – 238 million of US $ – (FAO, 2010). There are more than 6 endogenous breeds of sheep that have been identified in the country, each associated to a specific territory and to particular feed resources. In addition, there are numerous populations of sheep in marginal areas (particularly in the high mountains of the Atlas) which have not been intensively studied yet. This animal wealth represents a crucial asset for these marginal regions, as it constitutes the only way to get a source of income from shrubs and poor vegetation. Sheep breeding provides in these regions a vast array of products, not only high quality meat, but also wool which used to represent a good with high value as it allowed local handicraft to develop (mainly carpet production) and above all manure, which is crucial for soil fertility management, in agricultural systems generally not using fertilisers. Therefore, in high altitude sheep barns, manure is collected throughout the year, and then it is transported back on mules to villages (a hard task which is time consuming), where intensive crop cultivation is practiced (Bourbouze, 1997).

Previous works on sheep production in Morocco conclude that three distinct systems may be identified: *i*) extensive pastoral systems, which mainly depend on range land throughout the year, with a very limited contribution of cultivated resources, *ii*) agro pastoral systems, which rely on both range land but also cultivated resources (cereal straw, stubbles and grains, and sometimes fodder) and even extra farm resources (compound feed) for the flocks, and *iii*) oasis systems, which use mainly local feed resources (alfalfa, wheat straw and date residues) to raise a famous prolific breed (the D'man) within small flocks (less than 5 ewes with their progeny), as feed availability is limited in such a context (Boulanouar and Paquay, 2005). Recent evolutions in sheep production systems

Table 1. The use of cereal grains and its relationship to mutton and milk prices in Morocco (year 2000).

Concentrates/Total energy intake (%)	Type of concentrates	Prices comparison		
		Milk/barley	Mutton/Barley	Beef/Barley
15	Barley, wheat bran	1.5	30	25

Source: Adapted from Alary and Boutonnet (2006).

in Morocco recognise that there has been a shift towards two marked changes. The first one reveals that in all the flocks there is a trend of increasing cereal grains' uses, because prices policies tend to encourage mutton meat production through the imports of cheap grains, above all barley (Table 1). Such choices have implied a growing animal load in many range lands, which is raising concerns on natural resources' management (vegetation and soils' erosion) in fragile areas. This is particularly true in the arid areas of the East of the country and its South, which represent the vast majority of its range land territories (Chiche, 2006).

The second evolution consists in the emergence of the religious ceremony of 'Aïd El Kébir' as the main market for lambs, which imposes specific conditions for sheep breeders (Alary and Boutonnet, 2006). In fact, during that religious feast, each adult Muslim has to sacrifice a well conformed male lamb and it appears that it concentrates more than 50 % of all the sheep slaughtered annually. Therefore, sheep farmers have begun adapting to that evolution as they target that specific market to sell their products at good prices. However, for that religious ceremony, purchases of sheep obey to a strict protocol, as they have to respect religious texts. In fact, a key element in families' choices is the exterior appearance of the sacrifice lamb, which has to show particularly a well developed pair of horns. Therefore, all the strategies for the genetic improvement of sheep should take into account these specific requirements. This implies more interest to be attached to the standards of breeds, particularly by avoiding crossbreeding programs with hornless animals, as their products would not be accepted for that market.

The previous remarks show that sheep production in Morocco is facing increasing challenges. On the one hand, it is losing its 'natural' status, as growing numbers of flocks rely on off farm resources, even in range land, to feed ewes and their products. This also implies more tensions on the use of range land resources (above all shrubs and trees) which result in more soil erosion, because of the increase of the animal load, particularly in fragile arid areas. On the other hand, sheep products' demand is falling, as it is not competitive anymore with beef, dairy preparations and poultry products. This trend is clearly illustrated by the projections of the demand by year 2025, which have recently been presented by the agricultural authorities, as a component of the whole agricultural sector development goals (Agricultural Development Agency, 2008). These trends demonstrate that mutton's levels of consumption are expected to remain constant, at a time where most of the increases of the consumption of animal proteins should come from poultry and dairy products, and also beef (Table 2).

Table 2. Animal products' projected levels of consumption by year 2025.

Animal products	Consumption levels by year 2025 (in comparison to 2005)
Milk	Increase by 200 to 300 %
Meat (all species)	Increase by 130 %
Beef	Increase by 100 %
Mutton and goat	Same level
Poultry meat	Increase by 150 %

Source: Adapted from Agricultural Development Agency (2008).

However, sheep products have strong identity roles, as they are associated to important feasts, mainly the 'Aïd El Kébir' (Ibrahim's sacrifice rite) and baptisms. Therefore, sound efforts to promote extensive sheep production from remote areas in Morocco are needed. They should primarily focus on capturing consumers' interests by the promotion of their 'organic' and 'green' status in comparison to intensive systems like dairy cattle and poultry. To do so, traceability will be required, in order to reward sheep breeders from marginal territories, which generally have to face harsh conditions in comparison to sheep products raised mainly with cereals' straw and concentrates in suburban belts. To ensure that traceability and increase the income of extensive sheep systems, an improvement of the whole governance within that chain must be implemented, involving all the operators: from inputs' suppliers to breeders, retailers, supermarkets and consumers' organisation. That might represent a mandatory condition to ensure the sustainability of extensive sheep farming.

Concluding remarks

The ongoing changes in the social demand of animal products in Morocco have created a situation in which local products from extensive systems appear to be losing ground in front of goods (meat, milk and eggs) generated by intensive systems. In fact, the demand has shifted towards broiler meat and dairy preparations, which are more suited to fast food outlets' uses in comparison to mutton. Therefore, local authorities have promoted several measures to develop these intensive systems, by helping private poultry operators to settle modern facilities and by implementing a 'Dairy Plan' in the large scale irrigated schemes. The initial results have proved to be satisfactory, as the output of broiler meat, eggs and milk has increased significantly. However, a more cautious approach to these increases show that they rely on intensive imports of inputs, not only feed grains and protein meals, but also genes (heifers, chicks, and artificial insemination straws). Moreover, these intensive livestock and poultry systems are concentrated in specific areas (irrigated schemes for dairy farms and suburban belts for poultry facilities) which imply serious environmental concerns. For example, dairy farming needs important volumes of water (more than 1.7 cubic metres per kg of milk) and therefore, even in irrigated areas, it contributes in several regions of the country to the phenomenon of groundwater depletion. This is a question of serious concern in the vast majority of irrigated schemes located in arid and semi-arid areas (mainly in the South and the East of the country) where water stress is progressively causing the exodus of large dairy farms to more favourable areas in the North of the country. Another point of concern related to intensive dairying is its uses of pesticides to increase fodder biomass (mainly through maize silage) and to try to improve water productivity through cattle rearing. The impacts of such behaviours on the contamination of milk by pesticides' residues seem however to be ignored by the operators of the dairy chain, from dairy farmers to milk processors and, above all, consumers.

In order to promote the emergence of environmental issues within the animal products' supply chains, there must be a change in the methodological approaches used. A more systemic approach should be adopted, as it should consider not only the comparison of animal products' prices, but also their environment footprint (energy and water mainly in a country with no fossil oil and with acute water stress) and their social cost. Such a systemic approach might prompt significant evolutions in the roles of extensive livestock systems, situated in the marginal areas of the country. In fact, currently they have lost their prestige as they could not follow the growing quantitative needs of animal proteins in big cities. However, given the organic status of most of the products originating from range lands (above all sheep and goat meat), they could gain further interest for well-informed consumers, who desire to avoid the environment and health risks associated to products from intensive systems. Such an evolution can be vital to the resilience of the extensive livestock systems, as it would allow the increase of farmers' income and the rehabilitation of marginal areas of the country which face today important challenges like unsustainable rhythms of resources' uses (mainly forests and water), massive pauperization and rural exodus. To avoid the exacerbation of such problems and to promote a harmonised development of the range land areas of the country, the implementation of the traceability of their products must be adopted. This will encourage many consumers who

are becoming aware of the benefits of such products in comparison to goods from intensive systems to consent to pay higher prices. That can only reward the efforts of the livestock breeders in remote areas, who often have to face difficult conditions. To achieve all these goals and to balance the value repartition within extensive livestock systems' supply chains, the adoption of good governance will be compulsory. That might be achieved only with the responsible implication of all the operators (breeders' association, retailers, consumers and State authorities), who have to be aware of the crucial importance of this issue: rescuing extensive livestock systems to diminish the dependence on imported inputs and to promote a sound social and economic development of the wide pastoral areas of the country. This would also allow avoiding, to a certain extent, the consequences of the increases of food prices surge in global markets on the supply of the population.

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“And facing this urgency, let’s plan the next meeting first.”
Drawing by Robert Rousso. © MAR/S INRA

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Price : 15,24 € (P) ; 22,87 € (G) or 26 € (New)
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