Towards sustainable agriculture

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Forum [Foro]

TOWARDS SUSTAINABLE AGRICULTURE †

[HACIA UNA AGRICULTURA SOSTENIBLE]

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SUMMARY

Background: A large part of the society as well as the scientists and actors in the field of agricultural and food systems consider that a profound transformation is necessary to reach more sustainable systems of production. This position is new and requires deep changes for this transformation. **Objective:** To share the possible potential new approaches to transform our agri-food systems towards more sustainability. **Methodology:** Traditionally, sustainability is assessed via three main dimensions: economic, environmental and social. This is what we consider here. **Results:** In agri-food systems, it is possible to identify each one of these dimensions, from the producer to the final consumer, and to identify elements to improve their sustainability. A simultaneous approach to all three dimensions is essential. A few examples from unsustainable crop and livestock production systems make it possible to approach the attitude to adopt, then to identify the paths of progress and concretize these approaches **Implications:** The above transformations will not occur spontaneously but will be a long and difficult process which will require profound modifications in the ways of thinking, especially in young actors. **Conclusion:** It is urgent to develop sustainable agri-food systems and essential to develop holistic approaches using simultaneously all the levers at our disposal, rather than using them separately. In intertropical areas, if there is water available, it is probably possible to develop truly new systems through ecological intensification. Industrialized countries should also develop a capacity for innovation that challenges their current monospecific systems, by reassociating crop and animal production

Keywords: Agri-food systems; sustainability.

RESUMEN

Antecedentes: Gran parte de la sociedad, así como los científicos y actores del ámbito de los sistemas agrícolas y alimentarios, consideran necesaria una profunda transformación para alcanzar sistemas de producción más sostenibles. Esta posición es nueva y requiere cambios profundos para esta transformación. **Objetivo:** Compartir los posibles nuevos enfoques potenciales para transformar nuestros sistemas agroalimentarios hacia una mayor sostenibilidad. **Metodología:** Tradicionalmente, la sostenibilidad se evalúa a través de tres dimensiones principales: económica, ambiental y social. Esto es lo que consideramos aquí. **Resultados:** En los sistemas agroalimentarios, es posible identificar cada una de estas dimensiones, desde el productor hasta el consumidor final, e identificar elementos para mejorar su sostenibilidad. Es esencial un enfoque simultáneo de las tres dimensiones. Algunos ejemplos de sistemas de producción agrícola y ganadera insostenibles permiten aproximarse a la actitud a adoptar, luego identificar los caminos de progreso y concretar estos enfoques. **Implicaciones:** Las transformaciones anteriores no ocurrirán espontáneamente, sino que serán un proceso largo y difícil que requerirá modificaciones profundas en las formas de pensar, especialmente en los actores jóvenes. **Conclusión:** Es urgente desarrollar sistemas agroalimentarios sostenibles y es esencial desarrollar enfoques holísticos utilizando simultáneamente todas las palancas a nuestra disposición, en lugar de utilizarlas por separado. En las zonas intertropicales, si hay agua disponible, es probable que sea posible desarrollar sistemas verdaderamente nuevos a través de la intensificación ecológica. Los países industrializados también deben desarrollar una capacidad de innovación que desafíe sus actuales sistemas monoespecíficos, reasociando la producción vegetal y animal.

Palabras clave: Sistemas agroalimentarios; sostenibilidad.

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INTRODUCTION

The necessary transformation of agricultural systems towards more sustainable systems is now accepted as a medium- or even short-term perspective by a large part of scientists and actors in the field. This evolution is taking place under the influence of various constraints that are now identified and recognized by society as a whole. The first two in terms of importance for the future of our society and the future of our children, which I would place on an equal footing, are climate change and the collapse of biodiversity. Agriculture is both partly responsible for the climate changes observed on the surface of the globe and one of the solutions to slow down or even stabilize the evolution of these (Conférence des Parties COP28, 2023). It is also the modifications of agricultural systems and their impacts on life that are partly responsible for the unprecedented collapse in the history of the Earth of biodiversity (Benton *et al.*, 2021).

The situation is very serious on both points and despite the now old and repeated warnings of Intergovernmental Panel on Climate Change (2023) and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019), the reversal of trends towards a deterioration of the situation has not yet taken place regarding agriculture. However, we have both a fairly complete inventory of the links between agriculture, climate change and biodiversity and proposals for changes to our agricultural systems or new systems with less environmental influence, and therefore more sustainable than existing systems.

Thus, in the present text we will, first of all, share with the readers a common definition (Purvis *et al.*, 2019) of what is exactly sustainability of agri-food systems, then we will give some examples of unsustainable systems and the ways we can use to transform them. In a third part we will examine what could be our attitude towards current systems and in a fourth one the necessary holistic approach leading to sustainable systems, before ending with a final example combining research and development in Mexico.

Our final objective is to propose to readers a reflection about tools to reduce the footprint of our actual agri-food systems on our planet, while maintaining production capable of feeding its inhabitants.

SUSTAINABILITY OF AGRI-FOOD SYSTEMS

Conventionally, sustainability is assessed via three main dimensions:

First of all, economic sustainability. A system is not sustainable if it is in financial deficit in the medium and long term. The various actors in the agri-food chain, farmers, agri-food industries, distributors, consumers must be able to make a decent living from their profession. This is obvious, but you are well aware, even if you have not studied the economics of the agri-food chain, that this is not always the case and that the distribution of added value is often not very equitable between the various links in the chain (Filippi and Chapdaniel, 2021). In some countries producers have quite zero funding to invest in their system while all the profit goes to the other sections of the chain. Some other countries keep importing “cheap” commodities (i.e. milk, eggs, mutton, etc.), collapsing local markets in different regions where producers are eliminated from the equation. This is undoubtedly one of the main current problems of agriculture and agri-food which are underfunded in favour of distribution and consumption (Filippi and Chapdaniel, 2021). This unequal distribution, due to insufficient funding, slows down the necessary agroecological transition of agricultural systems by preventing investments by producers or the agri-food industry. I insist on the fact that this sustainability goes down to the purchase price of products by consumers. A system where selling prices are insufficient and do not allow a fair remuneration of the various steps in the production chain is also not sustainable. This notion of sustainability must also include losses and waste up to final consumption. A system where about 40% of production is lost, the figure most often cited, whether at the beginning or at the end of the chain, cannot be considered sustainable (Delgado *et al.*, 2023; Wani *et al.*, 2023).

The second dimension is environmental sustainability. It is certainly this dimension that is historically at the origin of the notion of sustainability (Purvis *et al.*, 2019) and which is probably the one that concerns us the most in agriculture. The aim here is to consider that for a system to be environmentally sustainable, it must borrow from the environment the inputs necessary for its operation and production, and then return them to the environment without altering them, “being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged” (Johnston *et al.*, 2007). As far as agricultural systems are concerned, these are first all inputs considered so far as free because they are present on Earth in supposedly unlimited quantities and accessible to all. It is mainly solar energy, air and water, essential inputs for plant photosynthesis and, therefore, leading to agricultural production. More recently, and since the "modern era", inputs are now bringing together three additional things (Chauveau *et al.*, 2013): (1) chemical fertilizers that mainly consume energy for their synthesis and contain nitrogen, phosphorus and potassium (the famous triptych N-P-K), (2) synthetic plant and animal protection products now essential in intensive agriculture and (3) the exploitation of knowledge on genetic variability and modes of transmission of the genetic heritage of plants and animals.

When human societies were "Hunter-Gatherer" more than 12,000 years ago, humans only indirectly used the first category of these inputs by taking plants and animals that had been transformed into consumable products (Chauveau *et al.*, 2013). The situation changed with the Neolithic revolution, around 11,000 years ago when, in different parts of the planet, domestications of plants and animals were associated with a sedentarization of populations. The most successful of these domestications (Cucchi and Arbuckle, 2021) have led to the current very input-intensive agricultural systems whose design, production and use have so far not integrated the absolute necessity of sustainability.

Thus, the air they use is often returned with an increase in carbon dioxide, methane and nitrous oxide, three particularly powerful greenhouse gases partly responsible for global warming. The water leaving farms, or farms returns to the natural environment often richer in nitrates or compounds which, not only could be useful if they were recovered and recycled on the farm itself, but are also harmful in the natural environment sometimes causing the proliferation of green algae in aquatic environments (Huang *et al.*, 2011) and sometimes the sex change of certain fish or amphibians (Devlin and Nagahama, 2002).

The intensification of the most "advanced" systems is also often associated with severe, lasting and ultimately irreversible damage to biodiversity. If we can easily imagine that climate change is reversible, a decrease in the concentration of CO_2 in the atmosphere leading to a decrease in the greenhouse effect, it is quite different for biodiversity. The disappearance of a single species is not, in itself, a new phenomenon because it is one of the known parameters of evolution, but the disappearance in a very short period of time of several dozen, even several hundred or thousands of them due to human activity, is much more worrying for the human species (Elewa and Abdelhady, 2020). It is from this biodiversity that we draw, first of all, our genetic resources in the medium and long term and it is this that keeps many of our agricultural systems in good functioning (Ortiz *et al.*, 2021). The disappearance of wild and domestic bees, which play an essential role in the pollination of cultivated plants, involves many agricultural productions. The scarcity of crop auxiliaries reinforces the need for the use of pesticides, which in turn kill these auxiliaries. More generally, the resilience of many agricultural systems depends on the biodiversity they contain (Ortiz *et al.*, 2021).

It is undoubtedly in this area of environmental sustainability that agriculture has, at the same time, a major responsibility for environmental damage and, also, an incredibly important task for the future. For example, for the carbon cycle, essential in the ongoing climate change, agriculture is both an important contributor to CO_2 and CH_4 greenhouse gas emissions, but also a carbon sink in agricultural soils that could strongly limit the phenomenon if it were better used. An important and rapid decrease in CH_4 emissions from ruminant livestock, which may be achieved by acting simultaneously on feed, on the rumen microbiote and on the cattle itself (de Haas *et al.*, 2021), would be very efficient on global warming because of the warming potential and very short half-life of CH_4 (El Mashad *et al.*, 2023).

Many authors use the concept of "closing" cycles for key input elements such as carbon or nitrogen (Kronberg *et al.*, 2021). The idea is to try to make the best use of the resources available on the spot to limit the import of these and to return these compounds on site also closing the cycle of the element considered. The example of nitrogen is particularly illustrative in some dairy, pig and poultry farming regions of Western Europe. A strong import of soybean meal from South America to balance the protein ration of high-producing animals, rather than local production, is economically interesting but has several disadvantages both in the territory of origin of the soybean and in the territory of arrival of the soybean. Soybeans, often genetically resistant to an herbicide, are intensively grown on land recently reclaimed from the forest or on very old grasslands, replacing ruminants themselves displaced on the latter, causing water and soil pollution by the widely used herbicide (de Oliveira *et al.*, 2018). At the same time, associated deforestation contributes to decreasing carbon storage and negatively impacts biodiversity (Strassburg *et al.*, 2010). In the receiving territories, excess nitrogen is spread on agricultural land already fertilized by chemical fertilizers, producing the appearance in groundwater and estuaries of environmental disorders harmful to human health or other activities such as tourism (Huang *et al.*, 2011). On-site closure of the nitrogen cycle would be one of the ways to reduce or even eliminate the problems encountered at both sites.

While agriculture can be blamed for a number of disorders such as those in the examples I have just described, it is also the source of hope for scientific, technical, economic and political solutions aimed at transforming agricultural systems into sustainable ones through what many scientists and members of society call the "agroecological transition" (Eastwood *et al.*, 2021). We know from History that several civilizations, probably very advanced in terms of knowledge of agricultural intensification and which probably used a lot of inputs, quickly collapsed perhaps because of a sudden shortage in water supply associated with many other causes such as wars and political problems. This is the case, for example, in North America in Teotihuacan (Park *et al.*, 2019), Caracol (Ertsen and Wouters, 2018), or in the large Mayan cities in Yucatan (Gill *et al.*, 2007), as well as in the Middle East for the Hittite empire (Manning *et al.*, 2023), or in Asia in Angkor where entire cities, of several hundred thousand inhabitants, very sophisticated in terms of production and distribution of agricultural products, have disappeared in a very short period of time. Historians tell us that these collapses were particularly brutal and associated with an "ecological decline" which may be linked to several consecutive periods of drought and be an element of complex events leading to collapse (Rull, 2016).

Even if history never repeats itself, these examples should inspire us to reflect and make every effort to transform our agricultural systems towards sustainable ones. Indeed, without being a follower of what is currently called "collapsology", which would like the collapses of civilizations to be brutal and dramatic, it seems to me that climate and biodiversity scientists have been warning us for several years now about much faster and greater changes than we could have imagined in the middle of the twentieth century (Intergovernmental Panel on Climate Change, 2023).

We will come back to this by giving some concrete examples of solutions to be applied or avenues of research to be explored in the fields of crop and animal production. There is no doubt that some solutions exist, even if the effort to be made to implement them is absolutely considerable.

The third dimension is social sustainability. It is a question here of considering that our production systems, in particular agricultural and agri-food, must allow a balance of inter-individual and inter-group relations of actors. Thus, a socially sustainable agricultural or agri-food system should not be based on the abusive exploitation of the labour used to make it work. This question is particularly important for two reasons. The first is that it is well known, and there are many examples around the world, that some very seasonal and intensive systems, at very low selling prices, are based on a human population that is often immigrant, poorly organized and easily exploited (King *et al.*, 2021). The second is that the main simulations made to carry out the agroecological transition we mentioned above, particularly with regard to the reduction or even elimination of pesticides, highlight that this can only be done by increasing the time of work in the fields (Solarte *et al.*, 2023). Even though some of this increase can be absorbed by the use of machinery, some tasks are not easily mechanizable yet.

The need for social sustainability also applies to the equitable distribution of surplus value along the various links in the chain of production-processing-distribution-consumption of agricultural products (Filippi *et al.*, 2021). Indeed, it is not just an economic question if the imbalance in this distribution leads to bankruptcies of agricultural enterprises, closures of processing plants or distribution stores. The unemployment induced by these economic disturbances therefore has social consequences.

Finally, we can also classify in the social sustainability of livestock systems the respect of animal welfare, which has emerged over the last twenty years in Europe as one of the essential factors in the evolution of both society's vision of livestock farming and the regulation of the conditions of production and slaughter of animals (Orihuela, 2021). Not worrying about the issue has become impossible and it is currently one of the most powerful drivers of the evolution of intensive livestock farming systems in Europe.

What may complicate matters a little is that these three areas of sustainability are by no means independent. If you try to improve one of them for a given system, you have to be careful that it does not lead to a deterioration of the other two. Thus, the implementation of agri-environmental measures must not lead to a deterioration in the economic or social sustainability of agricultural holdings. Fortunately, in many cases, if, for example, the reduction of inputs reduces crop yields and therefore crop turnover, the associated decrease in expenditure on the purchase of these same inputs often preserves the margin of the farm. But it's not always easy.

SOME EXAMPLES OF UNSUSTAINABLE SYSTEMS AND THEIR PATHS TO PROGRESS

At this stage I have remained quite theoretical and some examples of unsustainable systems must be given to know exactly what we are talking about. These examples are not lacking, unfortunately, and it is on the basis of reasoning that they can be identified, even if the following examples are deliberately simplified. For each of these examples, I will also try to give some clues leading to a possible better sustainability of these systems.

In the field of intensive bovine milk production, the continuous increase in individual production per cow has been achieved in recent decades thanks essentially to three simultaneous drivers: by targeting almost only quantitative production in the genetic selection criteria, by using hormonal stimulations with growth hormone in countries where it is authorized, and by providing animals with a diet with a high energy content (Capper and Caddy, 2017)). In this system taken to the extreme on an individual level, on the one hand milk production per cow is more than 10,000 kg of milk per year, which makes it possible to reduce greenhouse gas emissions per liter of milk drastically and to market the liter of milk at a very low price. On the other hand, the fertility of cows has been strongly impaired leading, in the most extreme cases, to the impossibility of renewing the herd, and metabolic disorders have increased, questioning farmers about respect for the well-being of their animals (Zachut *et* *al.*, 2020). These highly intensive systems are not sustainable and farmers are currently looking for ways to de-intensify their incomes while reducing the environmental footprint of their farms (van Wagenberg *et al.,* 2017). Taking into account criteria other than milk production alone, such as cow fertility, longevity and CH4 production in selection indexes, the use of grassland to store carbon and improve milk quality, better manure management limiting nitrous oxide emissions and reducing the use of chemical fertilizers, are among the avenues currently being followed (Brito *et al.,* 2021; Britt *et al.,* 2021).

Still in the field of dairy production, I would like to give the example of economic non-sustainability and then of an original solution that is currently incredibly successful in France. As in many countries where intensive dairy farming exists, this is the case in Western Europe, the prices of milk paid to the producer or paid by the consumer and the margins of the various actors in the chain from producer to processor are low: 0.47 USD/liter paid to the producer and 1.30 paid by the consumer to the retailer. This low and volatile remuneration of the producer by milk collection companies, whether private or cooperative ones, often below the cost price per liter of milk, has led to many closures of small farms, putting the whole system in danger (Thorsoe *et al.*, 2020). A private entrepreneur then implemented an original approach of consultation between producers and consumers, based on two questions: (1) "As a consumer, would you agree to pay a little bit more for your milk if it was produced in good conditions of sustainability and if you were sure that this extra price went directly into the farmer's pocket?" (2) "As a producer, if you were properly remunerated, would you agree to change your production conditions, including grazing and respect for animal welfare?" A milk producer receives about 0.20 USD more than for standard quality, which the consumer agrees to pay. A brand has been created "Who's the boss?", it supports more than 3,000 dairy farmers and is currently experiencing incredible success. Launched in 2016, it is now the best-selling milk in France (Les Echos, 2022). The principle has since spread to other brands that have been forced to follow regarding the milk but also butter, cheeses, eggs, etc.

In laying hens, in the same way as in dairy cattle, selection on the laying rate and the quantity of eggs produced per hen, the adoption of intensive breeding under artificial light regime with a high energy diet, has led to the existence of very productive lines with more than 330 eggs per hen per year for a very high feed yield of 2 kg of feed per kg of egg. The egg is today an extremely consumed product in the world and provides good quality animal protein accessible at a very low price (Gautron *et al.,* 2021). Similarly in broilers, selection on growth rate and the amount of meat produced, under rearing conditions similar to laying hens, made it possible to produce chickens weighing 2.5 kgs in less than 40 days. Poultry meat is highly valued for its quality and low cost to provide quality animal protein to human populations with low purchasing power (Maharjan *et al.,* 2021). However, selection on the sole criteria of egg production on the one hand and meat production on the other hand has led to extreme specializations of very different animal populations. Males in "egg" lines do not produce meat fast enough and females in "meat" lines do not produce enough eggs. Male chicks of the "egg" lines and females of the "meat" lines are therefore eliminated from birth. At least in Europe, this situation is not considered sustainable and the prohibition of these eliminations is now imposed by regulation (Gautron *et al.,* 2021; Le Monde, 2022). A short-term solution lies in sexing the chicks in the egg before birth, and then destroying the eggs of one sex or the other. Several non-invasive methods are currently being implemented in different European countries (Ruth and Jakobsen, 2023). In the medium term, the selection of mixed lines producing eggs and broilers would certainly be a more acceptable way (Gautron *et al.,* 2021), but it still seems economically difficult without a significant increase in the selling prices of the products. One could imagine an approach similar to that of "Who's the boss?" that I just reported for milk.

In the field of cereal production, there has been a dramatic increase in yields per hectare in Western Europe and elsewhere over the past fifty years. Thus, the yield of wheat increased from 1.5 tons/ha in 1945 to more than 7 tons/ha in 1995. Yields have plateaued since then. This dramatic increase is due, as in dairy cows and poultry, to the combination of genetic progress and a sharp increase in inputs, fertilization and plant protection products. It is also the consequence of a simplification of crop rotations leading to the almost uninterrupted succession of cereals from one year to the next on the same plot, to the detriment of other crops such as legumes (alfalfa, peas, etc.) (Meynard *et al.,* 2013). This simplification of rotations leads to poor control of diseases and pests that find favorable ground in the successive monoculture of wheat in particular, which leads to over-use of phytosanitary products, as well as poorer management of nitrogen in the soil over the long term, associated with increased water pollution (Meynard *et al.,* 2013). The simple reintroduction of a legume crop into the rotation one year out of 5, combined with a small sheep farm, has been shown to maintain or even improve the gross margin of the farm, mainly through the savings generated by the reduction in purchases of inputs such as plant protection products and nitrogen fertilizers (Meynard *et al.,* 2013).

In goat milk production, in France, the use of hormonal treatments, combining sponges and injection of PMSG-eCG made it possible to set up artificial insemination in the 70s and 80s and to use this means to select the best goats and bucks carrying favorable alleles of milk casein genes and thus increase milk production and cheese yield (Leboeuf *et al.*, 2008). These treatments also make it possible to obtain fertilizations outside the sexual season that extends in Alpine goat breeds, from September to February (Pellicer-Rubio *et al.*, 2019). These out-of-season fertilizations make it possible to produce more milk due to the lengthening of lactation and to sell it at a more favorable season in terms of purchase price to farmers. Every year more than 80,000 AIs are practiced using this technique and several hundred thousand goats are treated (Pellicer-Rubio *et al.*, 2019). However, the repeated use of these treatments in the same animals leads, in some of them, to the appearance of antibodies against PMSG that neutralize the effects of the injected hormone (Hervé *et al.*, 2004). Out-of-season reproduction of the entire herd is therefore difficult or impossible. In addition, production under the organic farming label is developing strongly in this species and organic production rules prohibit the use of exogenous hormones, thus excluding all organic farms from the national genetic improvement scheme (Pellicer-Rubio *et al.*, 2019). A solution to do without these hormonal treatments comes from the work carried out in Mexico within the Antonio Narro University for several years that I will present in the last part of this text based on the results obtained in Torreon (Coahuila, México).

The management of livestock disease resilience (Doeschl-Wilson *et al.*, 2021) and more especially that of internal parasites infections (Castaneda-Ramirez *et al.*, 2020) is also one of the major problems of sheep and goat farming, especially in grazing farming systems, whereas this system is the one that should be prioritized in terms of environmental impact. The use of synthetic parasiticides is a very effective solution in the short term and allows very quickly the suppression of the infections and the rupture of parasitic cycles. Unfortunately, due to the very high prolificacy of parasites and their ability to survive in the soil and vegetation of grasslands, genetic resistance of these same parasites to parasitic control quickly takes hold and it is now very difficult, if not impossible, to have effective molecules (Cameroon-Blake *et al.*, 2022). Many programs using alternative management, natural molecules and genetic improvement programs for sheep and goats are conducted in different parts of the world, including Mexico, the USA and New Zealand. The track of condensed tannins, present in legumes such as Sainfoin, is currently one of the most promising tracks. Nevertheless, it is towards a simultaneous use of the various tools above that we can probably achieve an integrated control of the parasitic infections of small ruminants (Simoes *et al.*, 2021; Torres-Fajardo *et al.*, 2021).

In the same way as in animal production, the production of fruit in orchards or grapes in vineyards is also subject to significant health constraints requiring repeated use of plant protection molecules. The latter, although increasingly effective against pathogens, are not completely specific and act on organisms beneficial to crops, leading to a loss of biodiversity that is useful to the production system (Schneider *et al.*, 2019). In this type of production, even if a genetic selection of plants on pest resistance is one of the indisputable ways of progress, the low speed of renewal of trees and the speed of resistance bypasses are obstacles to their implementation. However, many research programs are following this lead by developing multi-resistant lines, particularly with mildew in the wine sector (Schneider *et al.*, 2019). But they will have to be associated with the design of multi-species plant orchards, planted in such a way as to limit the speed of spread of pests and stimulate the populations of crop auxiliaries. (Lauri *et al.*, 2022)

WHAT ATTITUDE TOWARDS CURRENT SYSTEMS?

The first point concerns our attitude towards the agricultural and agri-food systems that we face in our professional lives. In saying this, I am thinking above all of the young colleagues trained by the universities who will find themselves, on the ground, facing questions relating to the sustainability of the systems of production, processing and distribution of agricultural products. But I am also thinking of university teacher-researchers and/or research organizations whose mission is to seek innovative solutions to improve the sustainability of these systems, but also to advise professionals in the agricultural and agri-food sectors in this quest for more sustainable systems.

It seems to me that by relying on common sense, on our knowledge, on our critical thinking and by carrying out an analysis based simultaneously on the three pillars of sustainability (economic, environmental, social), we can at least lay the foundations for a more in-depth analysis of the system in front of us. Then it will be necessary to try to correct the main defects of the system in terms of durability taking care that these corrections do not lead to degradation on the other pillars. It is said that a famous former Chinese leader said: "The Long March began with a first step!" (Lao Tseu, 2023).

The second point is a question that we are quickly confronted with as well: should we condemn all intensive systems or make them evolve towards more sustainability? Many studies have been carried out over the past fifteen years to understand what could be called a "global agriculture" and which aimed to try to find out if we could make agricultural production and consumption of human populations coincide in the simultaneous context of the increase in the latter (9 billion humans in 2050?) and the impact on the functioning of the planet (Guyomard *et al.*, 2021, Moran and Blair, 2021; Henchion *et al.*, 2021; Chatellier, 2021). One of these very first prospective studies, "Agrimonde" in 2010, showed that responding to such a challenge was possible provided we acted on all the levers at the same time: changing our diets and implementing an "ecological intensification" of agriculture (Ronzon *et al.,* 2011). Changing diets, combined with a reduction in loss and waste, would reduce both the pressure to increase production and reduce what nutritionists call the double burden of undernutrition and obesity (Detang-Dessendre *et al.,* 2020). Ecological intensification aims to stabilize yields in countries where they are already high and increase them in others by drastically modifying the use of inputs, especially from fossil fuels, and developing systems where the cycles of the main plant nutrients are closed (Bommarco *et al.*, 2018). Since then, many other studies, often contradictory, have appeared, but all, to varying degrees, propose to act simultaneously on these different components of the global agri-food system (Detang-Dessendre *et al.*, 2020).

The answer to this question is therefore that intensive systems must evolve towards greater sustainability. To see them disappear seems to me to be completely illusory and those who propose such an evolution do not seem to me to be realistic at all.

A NECESSARY HOLISTIC APPROACH TO SUSTAINABLE SYSTEMS?

The third point, finally, aims to discuss the necessary holistic approach to systems, again based on concrete examples taken in Latin America and in Africa. In the course of this text, I have given several indications aimed at improving the sustainability of systems by acting on one factor, then on another, etc. But some systems are, intentionally or not, organized in such a way that their overall impact in terms of impact on the planet is minimized from their very conception. I will take four examples, two from tropical Colombia, one from equatorial Africa and one from tropical Amazonia. These are all systems that could be described as "ecologically intensive systems". The first example is that of CIPAV, which has set up in a thoughtful and organized way, agro-sylvo-pastoral systems using, for dairy cattle production or "doble proposito" herds, strata of vegetation ranging from grazing grass to high-stem trees. In such systems where vegetation has water and solar energy at will, the results in terms of milk and meat production are incredibly higher (15 and 2.5 times!!) than in control pastoral systems using a single conventional fodder (Chara *et al.,* 2019). These systems also preserve biodiversity much better and impact the environment much less in terms of the release of excess compounds into the water or greenhouse gas emissions. The second example is also in tropical Colombia, on a farm in the Colombian hills (Finca Tosoly), and uses the principle that there should be no waste in the system, but that any by-product of it should be used as input by another production. It is an intensive circular ecology and the objective is to reduce the environmental footprint of the system as a whole. Thus, many crops and many animal species co-exist. They maintain close relationships between the different components of the system. Ruminants, pigs and poultry consume the by-products of sugar cane and tropical vegetables, while animal manure is used as fish feed and crop fertilizers. Water is recycled and the only products that leave the farm are for human consumption. The overall balance of the farm in terms of environmental impact is incredibly positive since its carbon footprint is negative (it stores carbon) and it improves soil fertility (Preston and Rodriguez, 2014). The third example is the result of an in-depth reflection aimed at setting up an autonomous aquaculture system that would use almost only solar energy. It is in Senegal. Omnivorous fish, the Tilapia species widespread and highly appreciated throughout the world, consumes zooplankton in tanks where recycled water circulates. Zooplankton consumes phytoplankton in suitable ponds, the latter benefiting from solar energy and tilapia droppings to grow. The cycle is not perfectly balanced, thus requiring the addition of a small annex cycle where Tilapias, not consumed by humans, consume Tilapia droppings. This allows the total balancing of the system. Ultimately, the system only requires a supply of water corresponding to evaporation during the different cycles (Gilles *et al.,* 2008). The fourth example was a repetition of the preceding one in the Peruvian Amazon with the Tiger Catfish (Gilles *et al.,* 2013).

These global approaches, which can also be called holistic, are based on a circularity of systems and close the cycles of the main input elements (Nitrogen, Phosphorus, Carbon) mentioned above. These are models that should be inspired, at least in humid intertropical areas where solar energy and water abound and where there is a high need for animal protein. But they are also good study models and sources of inspiration for researchers and professionals in a world very dominated by the monospecific production systems existing in temperate zones. It seems to me that too few researchers and professionals are currently drawing inspiration from it.

A FINAL EXAMPLE COMBINING RESEARCH AND DEVELOPMENT

Finally, I would like to give an example from the Comarca Lagunera (Mexico). In order to develop a useful research program for goat producers in the area, A. Narro University has tackled the description of the breeding characteristics of local goats and the environmental factors likely to cause them to vary. At the time, based on the limited amount of existing data on the distribution of kiddings in northern Mexico, the hypothesis was that seasonal feed supplies rather than daily illumination duration (=photoperiod) were responsible for the high kidding seasoning, leading to a poorly placed kidding period in the year. A research program has therefore been set up on this theme. It quickly became apparent that, contrary to initial hypotheses, it was the photoperiod that was the main factor responsible for the period of cessation of ovulations in goats and the low libido of bucks in spring (Duarte *et al.*, 2008).

After several experiments demonstrating, in both sexes, in an indisputable way, this photoperiodic control of the reproductive function, the research team tackled the development of "soft", non-invasive, cheap and easy to implement methods (i.e. most likely sustainable!) to induce out-of-season fertilizations (i.e. in spring) in goats (Delgadillo *et al.*, 2020).

The original idea in this field was to think that it was sufficient to treat only males with a simple photoperiodic treatment for two winter months for them to develop, a month and a half after, a "short sexual season" enough to induce ovulations and oestrus and fertilize goats in April-May, during which they are almost totally inactive. This use of sexually active males in spring works incredibly well since the fertility obtained is of the order of 80% (against less than 10% in controls with untreated male goats), the mortality of kids decreases (-15%), the surviving kids benefit from a higher selling price and the lactation was lengthened (+ 3 months) causing a higher milk production. A whole series of experiments have been carried out demonstrating the robustness of this simple, cheap and easy to implement technique among Comarca Lagunera breeders (Delgadillo, 2011; Delgadillo *et al.*, 2020).

This example is for me, a perfect illustration of the resolution by research for a question "from the ground" that has allowed breeders and the entire sector to improve their financial profits. Three years ago, it was estimated that 300 herds were using this technique, which generates an estimated additional income of about USD 45/goat, i.e. USD 4,000 per flock, which is considerable for small-scale livestock farmers in the area (Fuentes and Delgadillo, 2018, Person. Commun.).

It is also an example of the implementation of a research program that produces results that can be used in the field and that goes in the direction of a better sustainability of the goat systems of the Comarca Lagunera, from the farmer to the consumer through the manufacturer and marketing of Cajeta and kids.

CONCLUSION

Even if now all actors of the different parts of the agri-food systems recognize that we need to transform them towards more sustainable ones, not all of them consider that there is an extreme urgency and the majority of them does not know exactly how to perform this profound transformation. This challenge may be easier to meet than we think technically if we draw on existing relationships in natural ecosystems and if we consider, system per system, where the transformation should be done in the three dimensions of sustainability. However, if action is needed within each one of these three pillars, it seems me essential to develop holistic approaches using simultaneously all the three dimensions of sustainability, rather than using them separately.

In intertropical areas where solar energy is intense and abundant, if there is water available, it is probably possible to develop truly new systems through ecological intensification. We have seen very good examples of what can be done in this area even if the models are scarce, showing that a large way is open to innovations in these countries.

But the agricultural systems of industrialized countries, which are largely responsible of the actual situation regarding climate change and collapse of biodiversity, should also develop a capacity for innovation that challenges their current monospecific systems, by reassociating crop and animal production but also using more intensively potential relationships among species.

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