Food, agriculture and the environment

Agriculture and the environment: roles for technology and public policy

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Most environmental problems of agriculture can be traced back to different agricultural techniques. This relationship becomes clearer when we analyse the technological model as a whole rather than scrutinize individual agricultural techniques separately. The technological model includes not only the knowledge base used to generate innovative agricultural techniques to meet new challenges but also how these techniques are combined to do so (Bonny and Daucé, 1989).

A new technological model has emerged in post-war European agriculture (as well as other developed countries and, at a later stage, in many developing countries) to meet the challenge raised by the decline in agricultural labour force, as agricultural population was transferred to the expanding industry and service sectors. With labour increasingly scarce and respective opportunity costs rising, the productivity of labour in agriculture became the main thrust of the new technological model and its technical solutions.

Labour productivity in agriculture is the product of two factors: cultivated area per worker and productivity per hectare of cultivated land. Therefore, to increase labour productivity, the new technological model focussed on these two factors based on a double substitution:

- substituting human labour and animal traction by machines and motors, in order to increase the area of cultivated land per worker (the mechanical component of the model);

- substituting biological processes that occur in the agro-ecosystem (for example, atmospheric nitrogen fixation by soil bacteria being replaced by industrial chemical inputs, like nitrogen fertilizer), in order to increase the productivity of every hectare of cultivated land (the chemical component of the model).

Due to the equal importance of the model’s two components, it has been designated as the chemical-mechanical model (Bonny and Daucé, 1989). Both components were based on solid global advances in science and agronomy (in contrast to innovation based on local knowledge in traditional agriculture) and the use of large quantities of cheap fossil fuel energy to produce inputs, both mechanical (machinery and fuels) and chemical (industrial fertilizers and pesticides). As a result, agriculture has become highly dependent on this energy subsidy: in Portugal, the consumption of fossil fuel energy in agriculture to produce each Kcal of food energy was multiplied by ten between 1953 and 1989 - rising from 0.17 to 1.70 Kcal (Santos, 1996).

The new varieties of plants genetically improved as part of the chemical-mechanical model are generally very productive. However, this productive potential is only demonstrated when these plants are cultivated in profoundly modified agro-ecosystems, where water and nutrients are found in abundance and there is little in the way of pests, diseases and other competing plants, due to the systematic use of pesticides.

A small number of these new, highly-productive plant varieties generated by modern agricultural science have been replacing a broad range of crops adapted to the local agro-ecosystems nurtured over centuries by the local knowledge of many generations of farmers. The genetic basis of the chemical-mechanical model became much narrower, which made the model, as a whole, increasingly dependent on the permanent availability of cheap energy, and thus vulnerable to increases in energy prices.

At the socio-economic level, the spread of the chemical-mechanical model meant agricultural production systems gradually became part of the market economy. Markets for agricultural produce, markets for new industrial inputs and also credit markets providing the capital to be invested in buying new inputs now frame most farmers' production decisions. Farmers (until then those most responsible for creating local knowledge which their production systems were based on) became dependent on global scientific knowledge, which was first held by the State and its system of rural research and development, then possessed by the commercial suppliers of new inputs.

The double substitution of the chemical-mechanical model allowed for greater food production per farm worker, which facilitated much of the population's move from agriculture to emerging sectors of industry and services. As such, it has given us the much-cherished freedom to choose our occupations. In addition to this, it has reduced the overall risk of food insecurity – nowadays food security has more to do with the inequality of income distribution than the shortage of food production potential.

The agro-ecosystems modified by the chemical-mechanical model are also very different nowadays. They produce more food, but are also more dependent on foreign energy subsidies to guarantee its own operation and stability. The fact that agro-ecosystems were made more artificial by the chemical-mechanical model made it possible to increase agricultural production during the second half of the 20th century mainly by increasing production per hectare (intensification) rather than by expanding agricultural area. This boasted obvious advantages in terms of less pressure to convert natural habitats into farmland. However, the inefficient use of chemical inputs led to major pollution problems, which are far from being just local. The use of nitrogen fertilizers has doubled the overall nitrogen cycle on earth (Vitousek et al., 1997) and the presence of bio-accumulated pesticides can now be found in remote areas, like Antarctica, where they have never been used.

Overall, the widespread nature of the chemical-mechanical model, even in developing countries (the so-called green revolution), has meant that cereal production has trebled since 1950, based on: (1) the adoption of high yield varieties of wheat, rice and maize, (2) the trebling of irrigated land area and (3) the 11-fold increase in the use of industrial fertilizers (Brown, 2004).

The challenges ahead

Today, the decrease in cultivated areas due to soil degradation or urbanisation, the unacceptable ecological costs of expanding cultivated areas at the expense of the remaining natural ecosystems (deforestation, biodiversity crisis and CO_2 emissions) and the need for increased agricultural production (to deal with demographic growth, changing diets in developing countries and the demand for agricultural raw materials for non-food purposes, such as biofuels) have set enormous challenges for the next half-century (Brown, 2004). It is worth asking if the chemical-mechanical model, which has helped us in the past, can overcome these challenges.

However, there are a number of issues with the chemical-mechanical model. First, the model's environmental footprint needs to be reduced, in terms of both pollution (including greenhouse gas emissions) and impact on the planet's biodiversity.

Second, the genetic improvement of plants seems to be falling short of expectations, in terms of growth response to fertilisers and pesticides, increased land productivity, reduced costs and controlled pollution. These limitations are related to the chemical-mechanical model's method for increasing land productivity, which focusses on concentrating most of the cultivated plant's photosynthesis' product on the grain, by using plants with a lot of grain and little straw, rather than increasing photosynthetic production of the agro-ecosystem as a whole. The fact is that plants need roots, stalks and leaves, and they cannot be made up only of ears and grain. As such, this impressive path of plant improvement has travelled so far that it is coming to a dead end without any alternatives of equal potential in the short or medium term having been found yet (Brown, 2004).

Third, the depletion of water resources today affects many agricultural areas, particularly in the most populated regions of the planet, such as China and India (Brown, 2004).

Fourth, the expected impacts of climate change on crop yield and water resources, especially in areas that already have low productivity, such as sub-Saharan Africa, cast doubt on our global agricultural capacity in the future.

Fifth, dependence on cheap fossil fuels, induced by the chemical-mechanical model, has made agricultural production vulnerable to energy scarcity, which is particularly important in the current context of rising energy prices. Figure 1 shows that, in Portugal, the prices of energy-intensive agricultural inputs (energy and fertilizers) have risen over the last seven years much more than the slight increase of intermediate agricultural inputs in general. Figure 2 shows the reduced use of these energy-rich agricultural inputs by farmers over the same period, in response to this steep price increase.

Figure 1. Price changes in intermediate consumption overall and in energy and fertilizer consumption in particular (Portuguese agriculture).

Source: INE (Statistics Portugal), Contas Económicas Nacionais.

1 Implicit price index of intermediate consumption (base year 2004)

Energy and lubricants

Fertilizers

Intermediate consumption

Figure 2. Volume changes in intermediate consumption volume overall and in energy and fertilizer consumption in particular (Portuguese agriculture).

Source: INE (Statistics Portugal), Contas Económicas Nacionais (base year 2004)

Intermediate consumption

Energy and lubricants

Fertilizers

Figure 3. Relationship between agricultural intensity and farmland biodiversity underlying the concept of High Nature Value (HNV) farmland.

Source: EEA (2004).

Biodiversity

Degree of intensity of agriculture

HNV farmland

Intensive agriculture

As there is not enough space in this chapter to look at all of these issues, we will discuss only one (agriculture's footprint on the planet's biodiversity) as a case study to raise awareness of the complexity of many of the environmental problems of agriculture.

Agriculture and biodiversity loss

Nowadays, alongside climate change, the loss of biodiversity is one of the most significant factors of global unsustainability. The main direct cause of biodiversity loss on a global scale is the destruction of habitats, particularly that which is driven by the conversion of natural habitats to farmland (Myers, 1997). According to the Millennium Ecosystem Assessment (2005), only biomes relatively unsuited to crop plants, such as deserts, boreal forests and tundra, have remained largely untransformed.

The levels of land productivity (agricultural intensity) associated with the chemical-mechanical model have made it possible to save natural habitats that would have been converted into farmland if a less intensive form of agriculture (using more land to produce the same) had been employed (Green et al., 2005).

However, in regions that have long been transformed by agriculture, like in the case of Europe, the overwhelming majority of the biodiversity under threat is in areas where low-intensity agricultural systems are the norm. In these cases, the intensification of production systems and the resulting artificialisation of agro-ecosystems are an important driver of biodiversity loss; abandoning agriculture and the resulting re-naturalisation of agro-ecosystems also lead to biodiversity loss.

In Europe, two thirds of threatened and vulnerable bird species are dependent on agricultural habitats, with 40% being affected by the intensification of agriculture and 20% by the abandonment of low-intensity farming systems (Tucker and Heath, 1994). Similarly, 15% of the area designated for conservation purposes under the Habitats Directive (35% in the case of the Western Iberian Peninsula) are natural habitats that are dependent on low-intensity agricultural management. This European farmland biodiversity is also in decline, but now as a result of the abandonment of low-intensity agricultural land use or its intensification (EEA, 2004) and not because of the conversion of natural habitats into expanding farmland.

These positive associations between extensive agriculture and biodiversity have led to concerns about maintaining low-intensity farming systems (Bignal and McCracken, 1996), which were later incorporated into the European Environment Agency's work on high nature value (HNV) farmland. According to the European Environment Agency, this HNV farmland occupies 15-25% of the European Union's utilised agricultural area (UAA). What these areas have in common is low levels of production intensity, a high level of biodiversity and two mutually exclusive threats to biodiversity: the abandonment of farmland management, including afforestation of HNV farmland, and agricultural intensification. The link between productive intensity and biodiversity is understood like a graph that associates the "peak" of biodiversity with an intermediate level (low but not zero) of farming intensity (see Figure 3).

As such, there are two distinct views on the relationship between agriculture and biodiversity: one, which is relevant at global level, is that the expansion of farmland is the main driver of biodiversity loss; the other, which is particularly pertinent to Europe and other older agricultural regions, is that agricultural abandonment and intensification (and not the expansion of farmland) are the main drivers of biodiversity loss.

These two perspectives offer diametrically opposed solutions for public policy on agriculture and conservation: one is the intensive use of areas with the greatest potential for agriculture, in order to save large areas of natural habitat for the strictest protection of nature (spatial segregation of production and conservation functions), an option largely taken in the USA, Australia and New Zealand; the second is employing less intensive farming, which needs larger areas, but where it is possible to make production and conservation compatible in the same multifunctional space (spatial integration of production and conservation functions), which is an option generally favoured by the EU.

The two perspectives are probably both valid in their respective geographical areas, where the duration of agricultural occupation is quite different. This is a good example of the complexity of agricultural and environmental problems, which demand different solutions in different places.

The role of technology: sustainable intensification?

Defined as raising the level of production per hectare rather than the amount of inputs per hectare, agricultural intensification may be the key to avoiding mass conversion of natural habitats into farmland as a result of the growing demand for food, bioenergy and biomaterials.

However, within the chemical-mechanical model, production increases per hectare were generally achieved in the past through increases in inputs, with the use of fertilisers, pesticides, water and energy increasing across the board over recent decades.

This increased per-hectare consumption of inputs has led to them being used less efficiently in agricultural production, thus making it necessary to increase the amount of input used to achieve the same production increase. This dwindling efficiency, the corresponding growth of waste and pollutant emissions, and the widespread increase of input consumption have caused a range of environmental problems, such as the eutrophication of aquatic ecosystems, the poisoning of food chains, the decline of groundwater levels and water flows and the emission of greenhouse gases by agriculture. In addition to this, this has often meant higher costs, lower-quality produce, lower competitiveness and greater economic vulnerability of agriculture as we reach the end of the cheap energy era.

As such, it seems appropriate to decouple the increase in production per hectare from inputs per hectare as much as possible. This change of direction would allow us to create an agriculture that could be more competitive, more environmentally friendly and more resilient to water shortages and rising energy prices. This change of direction, which may (or may not) become an alternative technological model to the chemical-mechanical model, has become known as sustainable intensification (Royal Society, 2009).

How much it is possible to decouple production per hectare from input use per hectare is not yet clear. There are certainly limits to this technological strategy of producing more with less, thus reducing trade-offs between the environment and the economy. These limits are more obvious in the short term, mainly due to so-called technological lock-ins.

For example, the full expression of the genetic potential of the plant varieties that we use nowadays in agriculture depends on simple agro-ecosystems (with reduced competition but also with less help from predators and parasitoids, leading to greater need for pesticides) and high levels of nutrients in the soil (hence copious fertilizing). This example illustrates the interconnectedness and resistance to change within the current technological model: it is not possible to change the individual techniques one by one; change needs a new, alternative technological model in which new techniques (based on particular knowledge areas not emphasised in the current model) combine to meet new needs and challenges.

In order to make the transition from the current technological model, there are at least two strategic routes we can predict that can lead us to decouple per-hectare production from per-hectare input use. The first of these is based on increasing the efficiency of input use through more precise input use in time and space; inputs should be used only at appropriate rates when and where they are really needed; this approach is generically described as precision agriculture, but it also includes new irrigation methods (e.g. sensor-controlled drop irrigation) and many other technologies. The second route (which is not necessarily an alternative to the first) is based on copying ecological processes (predation, parasitism and diseases, symbiotic nitrogen fixation, mycorrhizae, combinations of permanent and annual cultures, or pollination by insects) and redesigning agro-ecosystems so that these processes are promoted and used as ecosystem services that replace purchased industrial inputs (pesticides, fertilizers and energy).

It is possible to devise techniques that facilitate both routes. A good example is that of “economic threshold levels of attack” used to trigger pesticide application in integrated production as an alternative to pesticide application by “schedule” (i.e. regardless of the levels of attack) as was usual in the chemical-mechanical model. Economic thresholds mean not treating except when the level of pest attack allows us to predict that the cost of non-treatment (production loss) exceeds the cost of treatment (pesticide price plus application costs). This technique simultaneously increases pesticide input-use efficiency by applying them more selectively (first route), and, because it is less harmful for auxiliary predators and parasitoids (often more susceptible to pesticides than pests themselves), it also enhances ecological processes that do the same work as pesticides for free – thus replacing chemical inputs by ecological processes (second route).

The first route (efficient use of inputs applied in a more targeted and selective fashion) principally depends on innovative information technologies, including geographical information systems (GIS), and sensor technology (including remote sensing). The second route (substituting inputs with ecological processes) is based on a better understanding of how agro-ecosystems work. Both may also use biotechnologies to resolve issues of efficiency (e.g. draught-resistant, water efficient crops) or substitution (e.g. nitrogen-fixing plants), respectively.

It should be noted that many of the abovementioned innovative techniques already exist or are being developed. What does not yet exist is an alternative technological model that facilitates faster development of these techniques and encourages coordinated, complementary and synergetic innovations.

It is also worth highlighting an important difference between the two transitional routes towards a new technological model. A better understanding of the way agro-ecosystems work (second route) is a public good, economically speaking. Once this better understanding is available, it becomes free for any farmer to use it to improve their productive agro-ecosystem, making it difficult for those who produced the technology to be remunerated for their technological research and development effort. Because this is about knowledge, it is difficult to patent, to limit access to it and charge a fee for its use, which is why private investment in technological research and development associated with the second strategic route will always be necessarily limited.

On the other hand, increased input-use efficiency through more targeted use of inputs (first route) generally involves objects, equipment, software or seeds (in other words, private goods) that can be more easily patented and sold to compensate for the costs of technological research and development. So, the first route is naturally more attractive for private research investment.

This difference between the public or private nature of the final output of the technological research and development process explains why diverse branches of science and technology are at very different stages of development, when the lion’s share of research and development investment is private.

However, it is clear that public investment priorities in science often coincide with those in the private sector, which means that, contrary to expectations, the desirable complementary nature (division of labour) of private and public in funding technological research and development does not occur. This complementary relationship would involve the State giving priority funding to research that essentially generated public goods (such as knowledge about how agro-ecosystems work), where the private sector has no interest. For its part, the private sector would invest (as it normally does) in research that essentially produces private goods that can be patented (predominant in the first route, which focusses on the targeted use of inputs).

Vanloqueren and Baret (2009) use precisely this idea of a lack of complementary relationships to explain the incipient development of agro-ecological innovation when compared to the advanced situation of genetic engineering within the context of the agricultural research system.

The obvious conclusion is that, in the field of research, priority should be given to areas that produce non-patentable knowledge, such as that which refers to how agro-ecosystems function.

Role of public policy: compensating public goods and correcting market failure

Agricultural production occurs at the heart of modified ecosystems (agro-ecosystems) and not within a factory context that is totally divorced from nature. Therefore, agricultural techniques have major effects on environmental quality. Some of these effects are positive (e.g. biodiversity associated with low-intensity farming systems), while others are negative (pollution, habitat conversion and soil erosion).

Unlike the food produced from it, most of the environmental effects of agriculture are not bought and sold in markets. Farmers and the technological research and development system react most to market prices, which can compensate their efforts. Everything else (water quality, biodiversity, basic environmental sustainability as a whole) is a side effect of decisions made on the basis of prices. As such, the market systematically fails in the realm of environmental regulation in agriculture (at least if we compare with its role in food supply and demand regulation). The idea of the invisible hand, as suggested by Adam Smith (father of modern economics), where the decisions we make in our own individual interests ultimately generate maximum common good, would only really work if all the consequences of our decisions had a market price. As some of these consequences, such as the environmental effects of agriculture, are not (or even cannot be) exchanged in the marketplace, the invisible hand no longer leads to the maximum common good – something which is known as market failure.

Market failure, which is a concept that all sorts of economists accept, requires public intervention by the state. In this case, it requires public policies to deal with environmental sustainability issues in agriculture. These policies can take different guises, ranging from simple environmental regulation to product differentiation according to their ecological footprint, helping guide consumers' buying behavior towards sustainability; they also include direct economic incentives for farmers that produce environmental public goods.

In the rest of this chapter, some examples of these economic incentives will be discussed, particularly those related to the Common Agricultural Policy (CAP) and the European Union's nature conservation policy.

The majority of the measures to encourage agriculture to produce environmental public goods in the EU are included in the second pillar of the CAP (the so called rural development policy). Some of these measures were designed before 1992; however, rural development policy explicitly arose only within the context of successive CAP reforms between 1992 and now. It became the second pillar of the CAP in 1999 (Agenda 2000 CAP reform). Throughout this period, there was a successive "greening" of the CAP. The main political reason for this transition was the change in the very nature of CAP reforms since 1992.

The 1992 reform was justified in terms that were internal to the CAP itself: reform was needed to do away with food surpluses, which were one of the CAP's internal problems. As such, it reformed measures to deal with internal problems without changing either the objectives or the basis of the CAP's legitimacy as a public policy.

However, the 1999 and 2003 reforms were forged to address problems unrelated to the CAP, which were the EU's position in the World Trade Organization (WTO) negotiations and the financial implications of enlargement to the East, combined with a tighter budget constraint.

Now the CAP needed a new language to legitimise the new production-decoupled payments that the WTO demanded to make sure that income support to farmers would not cause market distortion. Deprived of their output-regulatory function, these decoupled payments now resembled pure political rents, where farmers received public money and society received nothing in return.

The language found to legitimise these new decoupled payments was that of the "greening" of the CAP itself: farmers would be paid to produce environmental public goods (biodiversity, climactic stability, landscape amenities) that the market would not pay for.

Meanwhile, alongside this transformation of the CAP, there were also new developments in the EU's nature conservation policy. The issue of community funding for the implementation of the Natura 2000 conservation network had blocked the negotiations of the Habitats Directive until 1992. Member States (such as Spain and Portugal) that predicted that a considerable part of their territory would be affected by this new conservation network demanded that EU funds were made available to compensate farmers who were affected by a policy whose conservation goals were, essentially, for the EU at large. Other funding needs arose, as the option of working with farmers, rather than against them, was also adopted by many environmental NGOs (e.g. Birdlife International and WWF).

The problem of EU funding for Natura 2000 was eventually resolved via the definition of the EU Financial Perspectives for 2007-2013. The solution adopted was based on Member States using existing funds (particularly the rural development fund) to implement Natura 2000.

In conclusion, in order to work with farmers and not against them, it became necessary to allocate sufficient funds to environmental public goods not paid for by the market. With agricultural policy needing the environment as a new basis for its legitimacy and conservation policies geared towards working with farmers and treating them as important players in nature conservation, the conditions for a "marriage" (if not for love then at least for mutual interest) between these two areas of public policy were created.

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