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Agro-ecology: different definitions, common principles

The term "agro-ecology" is becoming increasingly common in scientific publications, and is used more and more often to refer to a new agricultural model that could purportedly reconcile the economic and environmental challenges in agriculture. The associated definitions vary considerably though, which can cause a measure of confusion among this sector's professionals, researchers and the general public. This paper aims to clarify this concept's origin, scientific and technical foundations, and the challenges it entails. We will show that agro-ecology concurrently designates a scientific discipline, a set of agricultural practices, and a social movement, and that implementation will entail a change in scale and perhaps a paradigm shift.

Agricultural production methods have undergone radical changes over the past 60 years. Productivity per hectare and per worker has increased considerably as a result of mainstreaming mechanisation and chemical inputs (fertilisers and phytosanitary products). "Modern" agricultural systems are gravitating in other words towards maximising economic and productive efficiency, inter alia through plant and animal selection procedures geared to enhance productivity, and through homogenised production systems that can simplify landscapes and specialise regions. These agricultural systems have become seriously artificialised and in those systems, the environment is considered almost peripheral: both a substrate and a set of constraints that need to be addressed (related to the climate and parasites). This form of optimisation, however, entails negative environmental and indeed social[1] impacts: simplifying landscapes and rendering them artificial substantially depletes biodiversity; the massive use of synthetic fertilisers and phytosanitary products takes a toll on water quality; the agricultural sector depends heavily on fossil fuels and therefore releases substantial amounts of greenhouse-gas (GHG) emissions (21% of France's total in 2010, for instance). Moreover, a growing corpus of research is suggesting that using phytosanitary products affects farmer health[2]. Over and above these environmental impacts, the technical drawbacks (resistances, lower soil fertility, etc.) are starting to show. Similarly, the economics of conventional agricultural systems (heavier intermediate costs, capitalisation levels, etc.) can jeopardise their transmission and—in a volatile environment—their viability.

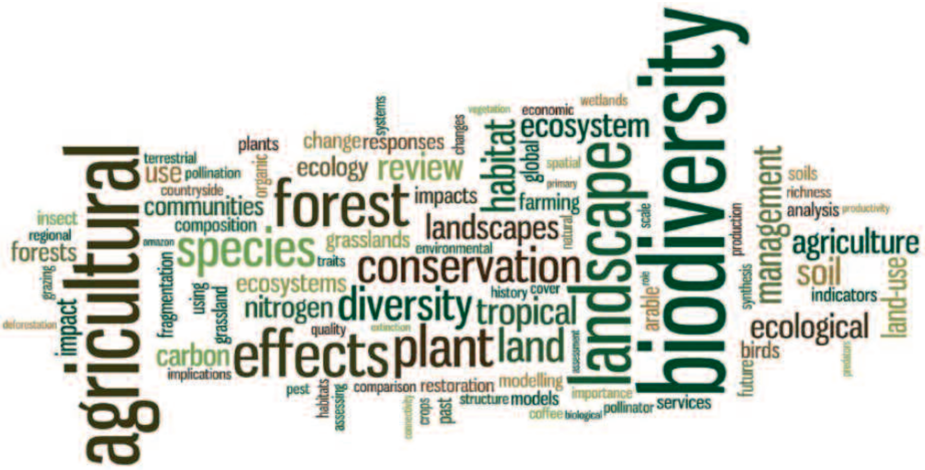
As a result the agricultural sector's drive to reconcile social and economic issues (in particular competitiveness) and environmental issues, more efficiently, effectively and sustainably, appears as a sine-qua-non today. Agro-ecology, which aims to create farming systems that harness functionalities provided by ecosystems, is gaining prominence—among researchers and a number of agricultural sector professionals—as one of the options. This paper presents the origin of the concept of agro-ecology and attempts to discern its main principles, beyond the variety of definitions it alludes to. Then, the main changes that implementing agro-ecological practices entails are discussed. The analyses herein draw substantially on three recent scientific reviews on this issue (Doré et al., 2011; Malézieux et al., 2012; Wezel *et al.*, 2009)[3] and on presentations on agro-ecology research currently underway[4] at the INRA gathering at the 2013 Paris International Agricultural Show.

1 - The agro-ecology concept's advent, success and diversity

The term "agro-ecology" was first used in the 1930s by Bensin[5], a Russian agronomist, initially in reference to applying ecological methods to research on crops. In 1965, German ecologist and animal scientist Tischler published what is most probably the first book titled Agro-ecology.

1. Cf.: *Millennium Ecosystem Assessment. Ecosystem and human well-being*. Synthesis, in: I. Press (Ed.), Washington, DC, p. 155.; Stoate C., Boatman N.D., Borralho R.J., Rio Carvalho C., de Snoo G.R., Eden P., 2001, "Ecological impacts of arable intensification in Europe". *Journal of Environmental Management* 63:337-365.
2. Cf. recent collective study by Inserm: http://www.inserm.fr/actualites/rubriques/actualites-societe/pesticides-effets-sur-la-sante-une-expertise-collective-de-l-inserm
3. Doré T., Makowski D., Malézieux E., Munier-Jolain N., Tchamitchian M., Tittonell P., 2011, "Facing up to the paradigm of ecological intensification in agronomy: Revisiting methods, concepts and knowledge" *European Journal of Agronomy* 34:197-210.
Malézieux E., 2012, "Designing cropping systems from nature" *Agronomy for Sustainable Development* 32 (1): 15-29.
Wezel A., Bellon S., Doré T., Francis C., Vallod D., David C., 2009, "Agroecology as a science, a movement and a practice. A review" *Agronomy for Sustainable Development* 29:503-515.
4. Cf.: http://www6.inra.fr/rencontresia/Toutes-les-rencontres/Agro-Ecologie
5. Bensin B.M., 1928, *Agroecological characteristics description and classification of the local corn varieties chorotypes*. Book. Cited in Wezel *et al.*, *op. cit.*

Figure 1 – **The most common key words in the titles of the 125 articles cited more than 100 times in the Web of Science (2002-2010)**



Source : INRA

Word size is proportional to the number of times it is quoted.

In that work[6], Tischler analysed the various compartments of the agricultural system (the soil, plants, etc.), their interactions, and the impact of human management of agricultural activities on each of these compartments. This approach in other words combines ecology (analysing interactions between biological elements) and agronomy (analysing agricultural practices). Generally speaking, the first agro-ecologists only had life-science backgrounds (zoology, agronomy, plant physiology, ecology, etc.).

Since the 1930s, the definition(s) of agro-ecology—and its scope—have evolved considerably. The original scale—a farm parcel—has grown substantially to encompass landscapes and sometimes even food systems. The approach has enhanced its focus from biotechnical sciences (agronomy, ecology) into a transdisciplinary approach including the social sciences. Comparing two definitions illustrates this change: in the 1960s, French agronomist Hénin defined agro-ecology as "ecology applied to plant production and farming land management"[7]; in 2003, Francis defined it as "the integrated study of the ecology of the food system in its entirety, comprising its ecological, economic and social dimensions or, more simply, the ecology of food systems."[8].

Scientific work on agro-ecology inflated noticeably in the 1970s and 1980s. From 1975 to 2012, INRA found 2,500 Web of Science publications containing the key word "agro-ecology", and more than 33,000 international publications containing related words (Fig. 1) from 2002 to 2011. During this period, agro-ecology also gained prominence worldwide, and spilled out of the confines of a scientific discipline or field of research to spur a number of rallies (in particular reactions to the "green revolution"[9]) and a set of agricultural practices. The experiences, across scientific circles, social movements[10] and agricultural practices, however, vary considerably from one country to another (see box).

These examples from around the world show that the notions of agro-ecology differ, in time and space, but nevertheless shed light on a few common denominators. From a "practice" perspective, agro-ecology can broadly be defined as a coherent whole that makes it possible to devise agricultural production systems that harness functionalities provided by ecosystems, reduce pressure on the environment, and protect natural resources. In scientific terms, agro-ecology can be defined as a discipline at the crossroads between agronomy, ecology and social sciences, with a preference for systemic approaches. Lastly, when they occur, agro-ecological movements tend to do so on the fringes of the predominant trend towards modernising agriculture, and promote rural development, food sovereignty, and environmentally-friendly farming.

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6. Tischler W., 1965, *Agrarökologie*. Gustav Fischer Verlag, Jena, Germany, 499p. Cited in Wezel *et al.*, *op. cit.*
7. Hénin S., 1967, "Les acquisitions techniques en production végétale et leurs applications", *Économie Rurale*, SFER, Paris, France, p. 31-44. Cited in Wezel *et al.*, *op. cit.*
8. Francis C., Lieblein G., Gliessman S., Breland T.A., Creamer N., Harwood, Salomonsson L., Helenius J., Rickerl D., Salvador R., Wiedenhoeft M., Simmons S., Allen P., Altieri M., Flora C., Poincelot, R., 2003, "Agroecology: the ecology of food systems", *Journal of Sustainable Agriculture*, 22, 99-118. Cited in Wezel *et al.*, *op. cit.*
9. A movement to modernise and intensify agriculture in many developing countries.
10. This term, borrowed from Wezel (*op. cit.*), is not used here strictly in the sense it has in political sociology but in its broader sense, i.e. stakeholder drives for innovative practices and projects.

Compared experiences in science, social movements and agricultural practices in four countries (based on Wezel *et al.*, *op. cit.*)

– In the US, scientists looking into pollution from agricultural sources initially explored agro-ecology. Their theoretical work spawned a fully-fledged scientific discipline (originally a life science, then a transdisciplinary one), which in turn spawned agro-ecological movements to promote rural development and environmental protection. These movements ultimately promote agro-ecological practices.

– In Brazil, it was the reverse. Agro-ecology started as a social movement for rural development and environmentally-friendly farming, as a reaction to drives to modernise agriculture, which were squeezing a number of farmers out: these groups were aiming to promote family-based farming and food sovereignty, and their actions triggered research into alternative practices (agro-ecological ones as well as organic farming), which in turn grew into a scientific discipline (inspired by that in the US and likewise embracing social sciences).

– In Germany, agro-ecology is almost entirely science with solid roots in top German universities. The definition has evolved little over time, insofar as German agro-ecology has always focused on the same scale, i.e. landscapes and not food systems (which include distribution channels, consumers, etc.).

– In France, agro-ecology is principally perceived as an alternative model within agriculture. It is mainly a set of practices. The study of agro-ecological practices has enhanced the discipline of "agronomy" in France, which has a systemic approach and a holistic vision of agro-ecosystems. Agro-ecology is gradually developing as a science, around a definition that resembles the German one as regards the scale (restricted to landscapes).

In the following section, we will focus on the scientific principles underpinning agro-ecology and illustrate them with the practices they inspire.

2 - Agro-ecology: the founding principles

According to Malézieux (2013)[11], the principal hypothesis underlying agro-ecology is that it is possible to increase agricultural output quantity and enhance its quality, manage pest populations more efficiently and effectively, and reduce reliance on inputs, 1) by increasing biological diversity in agro-ecosystems and 2) by optimising biological interactions in those agro-ecosystems.

It follows that the two pillars upholding agro-ecology, or "ecological intensification" as it is sometimes known, are enhancing biodiversity and strengthening biological regulations. High-biodiversity ecosystems are likelier to harbour multiple interactions and feedback loops linked to complex food webs. The term biodiversity here refers to functional biodiversity, i.e. not the number of species as such but the number of ecological functions that those species provide together. A few examples of agricultural practices illustrate the way in which these two principles can be applied[12]. These examples mostly concern health risk management and reducing input-reliance, but using functionalities provided by ecosystems also makes it possible to reduce pressure on the environment (e.g. soil erosion, GHG emission) and protect natural resources (e.g. by reducing energy or mineral fertiliser consumption).

Increasing natural, farmed or bred functional biodiversity

The goal, here, is to enhance biodiversity at various organisational levels, from parcels to landscapes.

At plant-cover level, increasing diversity limits bio-aggressor propagation (which is lower in heterogeneous covers). The associated practices can include planting associated crops (mixing cereals and leguminous plants, or grassland mixes for instance) or varietal mixes. Mixing wheat varieties, for example, noticeably reduces diseases[13].

At multi-parcel level, the goal is to increase plant-cover diversity and to play on population locations to diversify interfaces between covers and to recreate proper heterogeneity over space and time. Smart crop and/or cover rotation over time for instance reduces nitrate transfers. A diversified landscape mosaic helps to reduce the risks of parasites and therefore curb the system's reliance on phytosanitary products. This moreover fosters biodiversity and encourages pollination. Various practices contribute towards this goal: crop rotation/diversification, lengthening rotations, alternating winter and spring crops, introducing leguminous plants, cover plants and/or grass strips, adding trees, and building agro-ecological infrastructure such as hedges or groves. These semi-permanent features in the landscape provide shelter for beneficial insects, which prey on or parasite crop pests and can therefore contribute to fighting them using biological means.

L*astly, at farming system level*, the goal is to enhance production diversity in order to tap into complementarities between livestock and crops, and between livestock[14]. These interactions between crop systems and livestock systems (livestock effluents to fertilise crops; forage and litter from crops) have been discussed extensively and concurrently diversify covers and crops, and reduce the system's reliance on inputs.

Reinforcing biological regulation

The goal, here, is to foster biological regulation *via* food chains, i.e. by focusing on natural relations between populations to manage crop enemies. The principle involves promoting the first food-chain level (the crop) by limiting the presence of the second level (the predator) using a third one (the beneficial insects). It is important to provide an odd number of food-chain levels, i.e. three as in the example or even five (the beneficial insect's predator and the predator's predator). Biological regulations in agro-ecosystems for example promote seed predation to control weeds (with granivorous beetles, for instance), or to facilitate crop protection by harbouring beneficial insects nearby or even on the same parcels. The standard example of biological control is the ladybug, which preys on the greenfly, but there are many other examples of biotic interaction[15]. These complex mechanisms require sharp knowledge of the various species' eating habits, of how food chains work, of interactions between population dynamics and the landscape, etc. Considerable research on these issues will still be required, in particular to quantify the effect of agricultural practices and management modes on these ecological processes. As regards agronomic research, Doré et al. (*op. cit.*) underline the need to renew and diversify sources of knowledge (e.g. farmer knowledge) as well as analysis methods. They recommend using more meta-analysis to quantify production system performance variability in various soil and weather conditions, and comparative studies to identify the system characteristics that yield interesting properties.

The two main principles underlying agro-ecology (increasing biodiversity and strengthening biological regulation) afford the system several properties that help it to improve its durability: they in particular increase its resilience, i.e. its ability to reorganise and restore its initial structure and operation after a disruption. In that sense, agro-ecological systems can be more sustainable because they are less exposed to random biotic and abiotic fluctuations. Based on their characteristics, we can imagine that they contribute to significantly improving other environmental performances of agriculture. They can in particular contribute to managing water cycles, and nitrogen, phosphorus and carbon biogeochemical cycles more sustainably[16]. One limitation in these systems, however, may be productive performance: they may be only marginally sensitive to hazards but the trade-off could be, in some cases, lower food production[17]. Nevertheless, examples such as agro-forestry also show that higher biomass production per surface unit, generating more diversified revenues, is also possible.

In a nutshell, we can say that agro-ecology, as a set of innovative principles and practices, involves obtaining the most efficient and effective socio-technical arrangements in heterogeneous environments. The difficulty, in fact, is finding the right combination of practices to apply agro-ecological

11. http://www6.inra.fr/rencontresia/content/download/3244/32753/file/2Malezieux.pdf
12. Cf. Malézieux (2012), *op. cit.*
13. Source: Inra Grignon. Cf. presentation by Reboud et al. (2013) at the Paris International Agricultural Show: http://www6.inra.fr/rencontresia/content/download/3245/32756/file/3Reboud.pdf
14. Cf. Reboud *et al.*, *op. cit.*
15. Cf. literature review: Médiène S., Valantin-Morison M., Sarthou J.-P., de Tourdonnet S., Gosme M., Bertrand M., Roger-Estrade J., Aubertot J.-N., Rusch A., Motisi N., Pelosi C., Doré T., 2011. "Agroecosystem management and biotic interactions: a review" *Agronomy for Sustainable Development,* 31:491-514.
16. Cf. presentation by Richard *et al.* (2013) at the Paris International Agricultural Show: http://www6.inra.fr/rencontresia/content/download/3246/32759/4Richard.pdf
17. Cf. Malézieux (2012), *op. cit.*

principles and to maximise performances: simply overlapping practices does not add up to a system, so it is important to adapt the combination of practices to each local situation i.e. factoring in interactions between the system's components and practices.

Searching for efficiency, optimising current practices or substituting a specific practice with another rarely suffice to maximise performance and fully implement agro-ecological principles: it is more often necessary to redesign the system, and think again about its entire operation, to fulfil the new requirements.

3 - Does agro-ecology require a paradigm shift?

Implementing agro-ecological principles involves stepping beyond parcel and farm scales. Most of the environmental issues encompass larger areas and scales: maintaining biodiversity among habitats and landscapes, the quality of drinking water in a catchment area, watershed erosion, varietal resistance in production or collection basins, reducing GHG emissions on a global scale, etc. These space scales are delimited by both physical factors (watersheds) and human activities (collection basins). According to Reboud *et al.* (*op. cit.*), it is a question of "designing spatial and temporal organisations of agricultural activities and landscape structures, which suit the characteristics in the local environment, for farmers to benefit from the services provided by biodiversity and the surroundings, and to reduce the impacts on the environment."

This need to analyse the landscape and area scale instantly entails the need to think in terms of collective action—which may incidentally explain why social sciences have gradually woven their way into agro-ecology. It follows that action to set up green and blue ecological corridors or to recreate landscape mosaics need to be spatially coherent, and therefore require stakeholder coordination. For example, positioning agro-ecological infrastructure (hedges, grass strips, etc.) in a watershed significantly shapes environmental performance[18], explaining why farmers need to coordinate and decide together where to locate these features. The same applies to certain alternatives to insecticides such as mating disruption, which involves releasing large quantities of synthetic pheromones in order to deter male and female butterfly reproduction. This technique, which is often used in winegrowing operations, only works over single stretches of 10 hectares or more, meaning that several farmers in a same area need to cooperate. More generally, the recent report by Marion Guillou[19] commissioned by the Minister of Agriculture on double performance in agriculture recommends "developing new forms of solidarity between agricultural operations in rural areas." These new forms of solidarity will on the one hand involve managing livestock effluents at territorial level, and replacing mineral fertilisers with organic ones; and, on the other, developing and harmonising agro-ecological infrastructure to improve a number of environmental performances, as well as pooling certain mechanisation and labour costs. In all cases, these new forms of solidarity will be based on cooperation between farms, and perhaps between farmers and other stakeholders in the territory and business. In other words, they will hinge heavily on collective initiatives.

These initiatives may naturally stretch into wider rural development drives and involve other stakeholders that are not directly concerned by agricultural production, namely civil society, natural parks, land planning, tourism, environmental and other professionals, etc. The American definition of agro-ecology is broader than the European one, and covers every dimension of the food system, i.e. the distribution channels and consumers. The "social movement" aspect is also firmer: it promotes fairer and more sustainable rural development and food systems.

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In conclusion, despite the variety of definitions of agro-ecology and their considerable evolution since the 1930s, it is possible to identify several common principles: harnessing ecosystem functions to the maximum possible extent, maximising functional biodiversity and strengthening biological regulation in agro-ecosystems in order to sustainably reconcile social, economic and environmental challenges. At a recent seminar on agro-ecological system design, organised by INRA[20], other very complementary definitions were tendered: "agro-ecology is the application of ecology to the study, design and management of agro-food systems"; "it is not defined exclusively by scientific disciplines or exclusively by social movements, or exclusively by practices. It is due to become a rallying concept among these three dimensions."

There are nevertheless several hurdles to agro-ecology development. As the Guillou report points out, "regional specialisation paths are defined by powerful inertial drives and complex irreversible factors, inter alia due to the investments that need to be amortised." The change and transition towards agro-ecology therefore implies clearly identifying the factors determining current developments in the systems, fostering solid appropriation of the issues that a paradigm shift entails, and assessing the gridlocks and room for manoeuvre, in light of stakeholders' strategies and agendas. The research, training and development system, and public policy, have a major role to play in supporting this transition, and providing individual, collective and industry-level incentives. In effect, supporting and rallying the proliferation of grassroots initiatives, which the Guillou report highlights, the agro-ecological transition is now on the political agenda, in particular with the *Produisons Autrement* ("producing differently") initiative that kicked off in 2012, and on the research agenda, as agro-ecology has been added to the CIRAD's and INRA's top priorities.

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18. Downslope hedges have a more significant impact on water and nitrogen flows than watershed outlet hedges due to their greater interaction with the soil, water table and agricultural activities. Cf. Presentation by Reboud *et al.* (*op. cit.*).
19. Cf. report: http://agriculture.gouv.fr/IMG/pdf/Agroecologie_-_Rapport_double_performance_pour_le_MAAF_-_note_principale_et_annexes_-_VF_cle899e18.pdf
20. https://colloque.inra.fr/csaagroecologie2013/Programme

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