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Agricultural landscape heterogeneity, biodiversity and ecosystem services

Biodiversity decline threatens the production of ecosystem services and global food security. Among other causes, agriculture, deforestation and artificialisation contribute to this decline by fragmenting and shrinking natural habitats. Among the agro-ecological practices that make it possible to reconcile agricultural production and preservation of the environment, some are related to the structure of agricultural mosaics, at the farm or landscape level. This brief presents the main characteristics of these practices and, based on a review of the literature and an analysis of French land parcels, proposes a few courses of action.

According to the group of experts overseeing the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), nearly one million species are currently threatened with extinction worldwide[1], mainly due to overexploitation of wild species and agricultural development. In France, 76% of habitats and 59% of species of Community interest have an unfavourable conservation status.[2] Agricultural areas, which occupied 52% of mainland France's area in 2019[3], are particularly affected: 77% of grasslands had an unfavourable status over the period 2013-2018.[4]

The term "agricultural landscape" refers to all the fields and patches of semi-natural cover of one or more farms. They are not "landscapes" in the artistic or touristic sense of the term. The decline in biodiversity within these landscapes threatens the production of ecosystem services, which benefit society in general (water quality, beauty of areas, reduced risk of zoonoses, etc.) and farmers (pollination, biological control of crop pests, etc.). For example, the yields of 84% of food crops could fall by 25-32% if insect pollination no longer occur.[5]

Among the many agro-ecological practices that make it possible to reconcile agricultural production with the preservation of biodiversity and ecosystem services, some are related to the structure of the "crop mosaic", i.e. the distribution of crops in space, at the farm or landscape scale. This brief is devoted to them.

The first part introduces the ecological theories on the interactions between agricultural and natural environments, and their influence on agricultural and conservation policies. The second part then presents the recent scientific results on the links between crop mosaic heterogeneity, biodiversity and ecosystem services. Finally, the third part deals with this heterogeneity in France (arable land), based on an analysis of the data collected for the payment of the Common Agricultural Policy (CAP) subsidies. In conclusion, some avenues for public action are discussed.

1 - The representation of agricultural landscapes in ecology: a recent paradigm shift

The representation of landscapes as a combination of patches of semi-natural areas and a "matrix" of cultivated areas hostile to biodiversity ("island theory") has long dominated scientific work and influenced conservation policies. It has favoured "land sparing" management strategies of agrosystems and semi-natural areas, notably through the establishment of highly protected areas (see Box 1).

In parallel, most of the scientific research on the links between heterogeneity and biodiversity in agricultural landscapes has focused on the effect of semi-natural areas (hedgerows, grass strips, etc.) (Figure 1A).

1. IPBES, 2019, *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, IPBES secretariat.
2. European Environment Agency, 2019, *Conservation status and trends of habitats and species:* https://www.eea.europa.eu/themes/biodiversity/state-of-nature-in-the-eu/article-17-national-summary-dashboards/conservation-status-and-trends
3. SSP, 2020, *L'agriculture, la forêt, la pêche et les industries agroalimentaires*, Coll. Agreste GraphAgri 2020, MAA, Paris.
4. European Commission, 2019, *CAP context indicators. 2019 update:* https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/cap-context-indicators-table_2019_en.pdf
5. Zulian G., Maes J. and Paracchini M. L., 2013, "Linking land cover data and crop yields for mapping and assessment of pollination services in Europe", *Land*, *2*(3), pp. 472-492.

> **Box 1 - Land Sharing *vs.* Land Sparing management**
>
> Two land allocation strategies have been developed to promote food security while preserving biodiversity. They have been the subject of heated debates among researchers since the 2000s.[6] On the one hand, "land sparing" strategies would reduce the demand for agricultural land by increasing yields through the intensification of practices. On the other hand, "land sharing", based on the development of nature-friendly agriculture, would favour wild populations but would not optimise agricultural yields.
>
> Land sparing benefits species that are incompatible with intensive agricultural practices and land sharing benefits species that can survive in cultivated environments with agro-ecological practices. Thus, Kremen[7] argues for a "Both-And" approach, combining protected areas with rare, specialist, endemic, or area-demanding species and a "matrix" of farmland that itself supports biodiversity and provides ecosystem services. This mixed approach requires the identification of farming practices that are productive and benefit nature, and the establishment of protected areas.

Results show that increasing the amount of semi-natural areas in agricultural landscapes (e.g. proportion of wooded areas, length of hedgerows) increases the number of species in these landscapes.[8]

However, this management strategy has major limitations. Indeed, only a small proportion of the area can be set aside and human activities tend to impact the areas dedicated to conservation. In addition, it encourages environmentally damaging intensification in production areas. Nor does it take into account how the agricultural "matrix" influence the way individuals occupy patches of semi-natural areas and move between them: some species use cultivated areas partially, temporarily or exclusively, while others adapt to them over generations. Cultivated areas are therefore not a hostile "matrix" but a mosaic of ecosystems. The theory of "habitat-matrix" landscapes has therefore been progressively challenged since the 1990s, giving way to an approach based on "mosaics".

Biodiversity within agricultural mosaics is influenced by processes within agricultural plots (e.g. tillage, use of chemical inputs) and at the landscape level (e.g. diversity of plant cover). Cultivation practices, which modify the structure of agricultural mosaics, therefore affect biodiversity in these landscapes.[9]

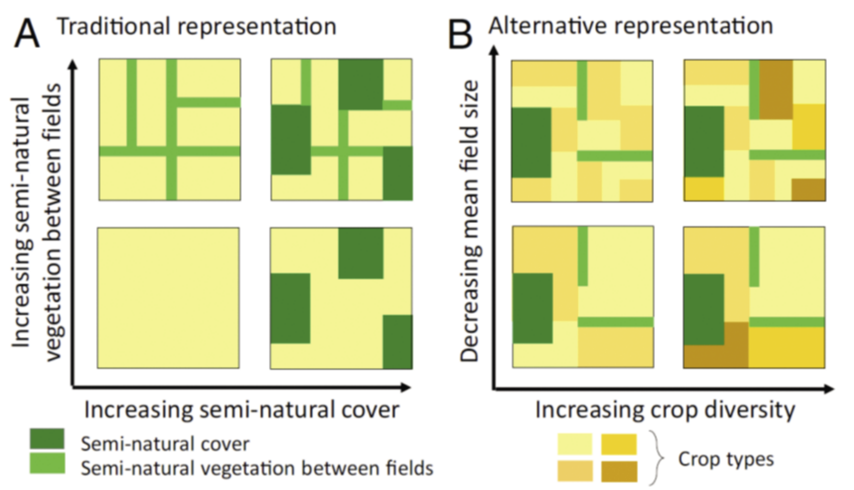
The heterogeneity of agricultural mosaics has two components: a) their *composition* (types of plant cover), which can be measured by the number of crops or by crop diversity indices that take into account their number and relative proportion; b) their *configuration* (spatial distribution of these covers), which can be estimated by the average size of plots or the length of interfaces between plots. A growing body of scientific research on the link between heterogeneity and biodiversity in agricultural landscapes is therefore now focusing on the role of crop diversity and plot size (Figure 1B).

2- The influence of crop mosaic heterogeneity on biodiversity and ecosystem services

Several recent empirical studies confirm the benefits of increasing the heterogeneity of the crop mosaic for biodiversity. With regard to plot size, a study in eastern Ontario (Canada) shows that its reduction has a positive effect on the diversity and abundance of birds, plants, butterflies, hoverflies, bees, carabid beetles and spiders in agricultural environments, all other things being equal.[10] A more recent study, conducted in eight contrasting regions of Europe and North America, confirms these results and shows that increasing the heterogeneity of the crop mosaic is as beneficial to biodiversity as increasing the proportion of semi-natural areas.[11] Thus, a reduction in the average plot size from 5 ha to 2.8 ha would increase biodiversity as much as an increase in the proportion of semi-natural areas from 0.5% to 11%. Studies focusing on certain families or taxa (birds, arthropods, bats, plants) confirm these results.

Crop diversity, in turn, influences biodiversity in two ways. First, increasing the number of crops in a landscape has a positive effect on total biodiversity at the landscape level, as different crops host partly distinct species assortments due to their specialization. Secondly, it favours certain species that need complementary resources available in different crops. In the

Figure 1 - Traditional schematic representation of heterogeneous agricultural landscapes, showing the role of patches of semi-natural environments and linear semi-natural elements between plots (A). An alternative representation takes into account the role of crop diversity and plot size (B).



Source: Sirami C. *et al.* 2019, "Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions", *Proceedings of the National Academy of Sciences*, *116*(33), 16442-16447.

6. Green R. E., Cornell S. J., Scharlemann J. P. and Balmford A., 2005, "Farming and the fate of wild nature", *Science*, *307*(5709), pp. 550-555. Phalan B., Onial M., Balmford A. and Green R. E., 2011, "Reconciling food production and biodiversity conservation: land sharing and land sparing compared", *Science*, *333*(6047), pp. 1289-1291. Fischer J. *et al.* , 2014, "Land sparing *versus* land sharing: moving forward", *Conservation Letters*, *7*(3), pp. 149-157. Loconto A., Desquilbet M., Moreau T., Couvet D. and Dorin B., 2020, "The land sparing-land sharing controversy: Tracing the politics of knowledge", *Land Use Policy*, *96*, pp. 103-610.

7. Kremen C., 2015, "Reframing the land-sparing/land-sharing debate for biodiversity conservation", *Annals of the New York Academy of Sciences*, *1355*(1), 52-76.

8. Batary P., Baldi A., Kleijn D. and Tscharntke T., 2011, "Landscape-moderated biodiversity effects of agri-environmental management: a meta-analysis", *Proceedings of the Royal Society B: Biological Sciences*, *278*(1713), pp. 1894-1902.

9. Agricultural practices that generate temporal heterogeneity in the agricultural mosaic can also affect biodiversity. They are not dealt with in this note.

10. Fahrig L. *et al.* , 2015, "Farmlands with smaller crop fields have higher within-field biodiversity", *Agriculture, Ecosystems & Environment*, 200, pp. 219-234.

11. Sirami, C. *et al.*, "Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions", *Proceedings of the National Academy of Sciences*, 116(33), pp. 16442-16447.

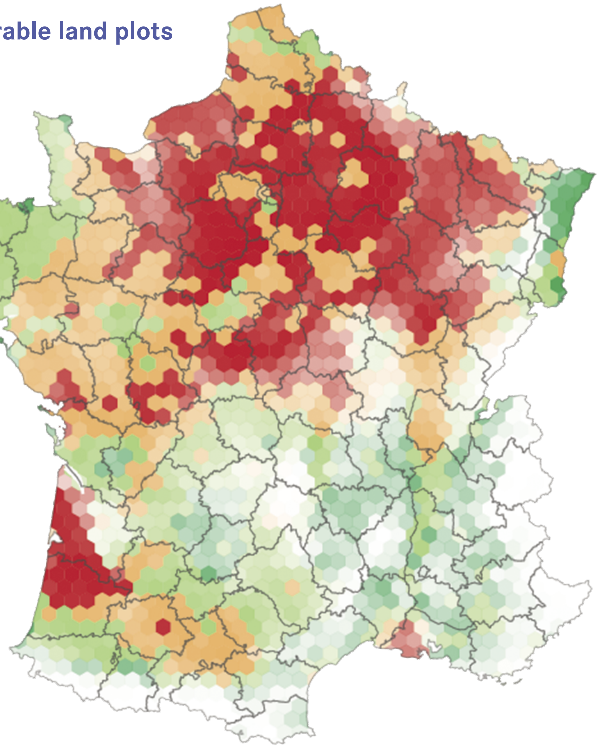
literature, the "plot size" factor has a more systematic positive effect on biodiversity than the "crop diversity" factor.

In addition to its effects on the biodiversity present in fields, the structure of agricultural landscapes modifies the production of ecosystem services. For instance, landscape simplification, by reducing the species richness of insects or natural enemies of crop pests, has cascading effects on pollination, biocontrol and crop yields.[12] Two studies show that agricultural landscapes with smaller plots favour higher levels of pollination.[13] Other studies confirm the positive impact of heterogeneous plot patterns on biological control and water quality, and the role of landscape structure in biological control.

3 - Degree of heterogeneity of crop mosaics in France

In France, the utilised agricultural area (UAA) declared to the CAP in 2018 is about 27 million hectares (Mha), for about 330,000 farms. The UAA is dominated by arable land (17 Mha, or 63.3%), permanent grassland and pasture (9 Mha, or 33.7%) and permanent crops (0.8 Mha, or 3.1%).[14] The dominant crop types are cereals and pseudo-cereals (39.0% of the UAA), permanent grassland (33.7%), oilseeds (8.8%) and temporary grassland (6.5%). At a finer level, the ten most represented crops occupy 78% of the total UAA. Soft winter wheat alone represents 18%. Crop distribution differs greatly between regions, with arable crops being particularly present in Île-de-France (97% of the UAA), Hauts-de-France (87%), Centre-Val de Loire (86%) and Brittany (80%).

Figure 2 - **Average size of arable land plots**



- 4.7 ha - 16.7 ha
- 3.1 ha - 4.7 ha
- 1.9 ha - 3.1 ha
- Less than 1.9 ha

Opacity: share of arable land in the UAA

The hexagonal cells measure 11.5 km on each side, or about 350 km². The more opaque a cell is, the higher the share of arable land in the UAA of this cell. NB: the Landes and the south of Gironde, although appearing in red, are not taken into account in our analysis because their UAA (as calculated excluding forests) is very low.

Source: CAP data, ASP 2018, processed by the authors

Average plot size in French agricultural landscapes

In France, the average plot size is 3.09 ha, all types of crops combined. It varies among crop types, crop families or crops. For example, it is 1.26 ha for permanent crops, 2.69 ha for permanent grassland and 3.63 ha for arable land. It is 4.38 ha for sunflower and rises to 7.57 ha for non-fodder beet (Table 2). Almost 50% of the plots are small (less than 2.1 ha), but very large plots (more than 6.8 ha) occupy more than 50% of the area.

The average size of arable crop plots varies greatly according to the regions and their dominant production. It is particularly high in Île-de-France (5.40 ha) and Centre-Val de Loire (5.22 ha) (Figure 2), these regions being major production areas for soft winter wheat (39% and 28% of their UAA respectively) and winter rapeseed (14% of their UAA), which occupy, on average, large plots of land throughout the country (Table 2). Finally, non-fodder beet, which is based on extensive mechanisation requiring large plots, occupies 9% of the UAA of Île-de-France, and is grown on plots of 7.57 ha on average.

Next come the Grand Est, Hauts-de-France, Normandy and Bourgogne - Franche-Comté regions, where the average size of arable plots exceeds 4 ha. In contrast, Brittany, which is also rich in arable crops, has small plots (2.58 ha on average), due to the dominance of livestock activities and therefore the presence of temporary grasslands and fodder (10% of the UAA), cultivated on small plots (2.12 ha on average in France).

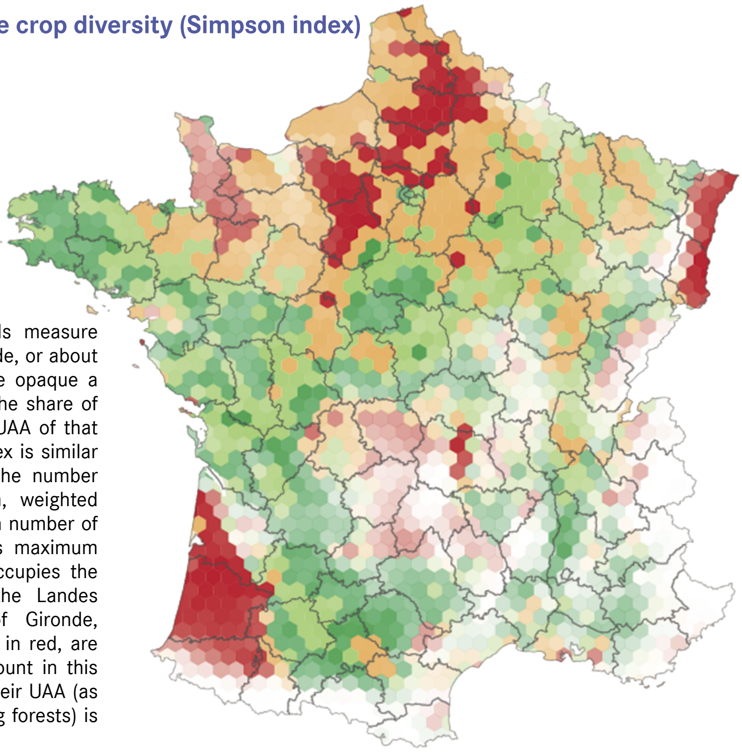
Table 1 - **Average plot size and total area of the 10 crops with the highest average plot size among the 25 most represented crops in the French UAA**

Arable crops	Average plot size (ha)	Total area allocated in the national UAA (ha)	Share of national UAA (%)
Non-fodder beet	7,57	496 382	1,86
Linen fibre	6,58	106 344	0,40
Dehydrated alfalfa	6,37	67 311	0,25
Winter rapeseed	6,07	1 612 277	6,03
Spring peas	5,39	103 305	0,39
Spring barley	5,38	481 899	1,80
Soft winter wheat	5,10	4 850 130	18,15
Winter durum wheat	5,06	347 750	1,30
Winter barley	4,40	1 284 015	4,81
Sunflower	4,38	550 369	2,06

Source: CAP data, ASP 2018, processed by the authors

12. Dainese M. *et al.*, 2019, "A global synthesis reveals biodiversity-mediated benefits for crop production", *Science advances*, *5*(10).
13. Hass A. L. *et al.*, 2018, "Landscape configurational heterogeneity by small-scale agriculture, not crop diversity, maintains pollinators and plant reproduction in western Europe", *Proceedings of the Royal Society B: Biological Sciences*, *285*(1872), pp. 20-172-242. Martin E. A. *et al.*, 2019, "The interplay of landscape composition and configuration: new pathways to manage functional biodiversity and agroecosystem services across Europe", *Ecology letters*, *22*(7), pp. 1083-1094.
14. Data from 2018 CAP declarations collected by the Agency for Services and Payments (ASP), processed by the authors.

Figure 3 - **Arable crop diversity (Simpson index)**



The hexagonal cells measure 11.5 km on each side, or about 350 km². The more opaque a cell is, the higher the share of arable land in the UAA of that cell. Simpson's index is similar to an average of the number of crops per farm, weighted by area. For a given number of crops, the index is maximum when each crop occupies the same area. NB: the Landes and the south of Gironde, although appearing in red, are not taken into account in this analysis because their UAA (as calculated excluding forests) is very low.

Source: CAP data, ASP 2018, processed by the authors

Crop diversity in French agricultural landscapes

The diversity of arable crops can be quantified, at the landscape level, by the Simpson index, which takes into account the number of crops and their relative proportion (Figure 3). It varies greatly among regions. Hauts-de-France, Île-de-France, as well as some areas of Grand Est, Centre-Val de Loire, Normandy and New-Aquitaine, are not very diversified, being highly specialized in certain field crops such as soft winter wheat, which occupies between 23% and 39% of their UAA. Conversely, in Brittany, the cohabitation of livestock and crop farming increases the diversity of crops, due to the large share of temporary grasslands and crops linked to animal feed in the crop rotation (e.g. silage maize).

Combination of size and diversity

These analyses show that Brittany, Occitania and the north of New-Aquitaine have on average small plots and high crop diversity. Conversely, several areas in Hauts-de-France, Normandy, Île-de-France, Centre-Val-de-Loire and Grand Est have both large plots and low crop diversity. In these regions, the low heterogeneity of agricultural mosaics could therefore be one of the causes of the observed decline in biodiversity. However, this contribution remains difficult to quantify: the state of biodiversity is influenced by multiple factors, either related to agricultural activity or not. Thus, climate change, land artificialisation and the use of inputs (e.g. pesticides) are all pressures on agro-ecosystems and the diversity of species they host.

However, the results presented in the second part of this note clearly show that the heterogeneity of agricultural mosaics has a positive impact on these areas' biodiversity. The impossibility of quantifying the relative weight of this factor in the loss of biodiversity should therefore not hinder its consideration in public policies and strategies implemented to preserve it. This is particularly true in areas with little agricultural diversity: monitoring the average size of plots and crop diversity, which are simple indicators that can be easily quantified with data currently available, would be a first step towards better measuring changes in agricultural mosaics. In the longer term, this would make it possible to better consider these factors in agri-environmental policies.

*

The abundant literature on the subject shows that agricultural landscapes structured in small plots and composed of diversified crops are more likely to host high levels of biodiversity and produce ecosystem services useful to farmers and society in general. Between these two factors, plot size has a predominant effect.

In France, for historical and pedo-climatic reasons, several regions that are highly specialized in field crops have large plots and low crop diversity. In these areas, increasing the heterogeneity of the crop mosaic, for example by limiting the size of plots, would help preserve the biodiversity in agricultural landscapes and achieve the European objectives of the Biodiversity and *Farm to Fork* strategies.

Some CAP instruments already aim to encourage crop diversity. This is the case of the green payment, which should be integrated into cross compliance in the next CAP. However, its level of ambition remains low and it would benefit from being higher: at present, a farm meets the crop diversity criterion with a Simpson index of only 1.75. The criterion on Ecological Focus Areas could also be revised to better target hedge planting, which mechanically reduces plot size. Crop diversity is also promoted by certain Agri-Environmental and Climate Measures (AECM), for instance those targeting field crops and imposing conditions on crop rotation. Yet, those are still seldom contracted. The AECM polyculture-livestock systems, which encourage the cohabitation of crops for livestock feed, meadows and cash crops, are also an interesting lever.

Beyond the CAP, other types of public action can influence the heterogeneity of the agricultural mosaic. Crop diversity and plot size could be the subject of agricultural, landscape and environmental policies at the local level, with, for example, payments for environmental services carried out by local authorities (e.g. municipalities, agglomerations). They could also be included in the specifications of origin and quality labels.

The impacts of the structure of agricultural land on biodiversity show the extent to which the agricultural production system has a multifactorial role in preserving the environment and producing ecosystem services, beyond other factors widely discussed, such as limiting inputs or lengthening rotations. The complexity of each of these factors and of their combination encourages a strong focus on the local level, since it will allow better taking into account the specificities of each local region.

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