Analyzing sociotechnical barriers and fostering innovation to diversify crop rotations in sheltered vegetable cropping systems in South-eastern France

Mireille Navarrete[a], Marion Casagrande[a,c], Arnaud Dufils[a], Amélie Lefèvre[b], Claire Lesur-Dumoulin[b]

[a] *ECODEVELOPPEMENT, INRAE, 84000 Avignon, France, mireille.navarrete@inrae.fr*
[b] *Agroecological vegetable systems Experimental Facility, INRAE, Alénya, France*
[c] *Université Paris-Saclay, INRAE, AgroParisTech, UMR SAD-APT, 91120, Palaiseau, France*

Abstract: Despite citizens and public incentives call for a deep reduction in pesticide use, the French market-gardening sector faces difficulties to implement agroecological cropping systems that use less pesticides, and in particular crop diversification, because it requires a deep redesign of cropping systems. How to favor the transition of large specialized farms, occupying main part of the total area, those that could enable a strong reduction in pesticide use? Two case studies were carried out in South–East France. Several actors in the agri-food system were interviewed to identify the current barriers to crop diversification. Six categories of barriers faced by market-gardeners were identified: agroecological inputs not or hardly accessible, lack of specific machinery and land, work-related barriers, lack of knowledge, and commercial difficulties. An outstanding result is that most barriers experienced by market-gardeners are linked to barriers experienced by other actors, which highlights a sociotechnical lock-in around the diversification of crop rotation for managing plant health. This information was later used to devise and carry out multi-actor workshops to co-design coupled innovations that enable farmers to overcome the barriers for implementing diversified crop rotations, with the main actors in the agri-food system engaged in the sociotechnical lock-in.

Keywords: agri-food system; sociotechnical system; actors; diversification; vegetable; market-garden

1. Purpose

Despite citizens and public incentives call for a deep reduction in pesticide use for health and environment reasons, the European market-gardening sector faces difficulties to implement cropping systems that use limited amounts of pesticides. Among agroecological practices, crop diversification has a large potential to lower pests and diseases damages. Diversified farming systems offer various ecosystem services, such as nutrient and water cycling, soil formation, pest and disease control, pollination, and production variability reduction (Kremen et al., 2012). Plant diversification covers a range of patterns, at various spatial and temporal scales: mixes of species and cultivars or large crop rotations at plot and farm level, agroforestry or agroecological infrastructures at territorial level. A recent literature review demonstrates the high potential of these patterns for controlling pests and diseases (Vialatte et al., 2023). In a study on cash crop farms, Guinet, Adeux et al. (2023) showed that total pesticide use was reduced in crop rotations where functional and taxonomic diversity was higher. Despite public policies aiming to reduce pesticide use (e.g. Green Deal at European level, Ecophyto plan in France), largest reductions in pesticide use are in organic farms or those selling vegetables in short value chains. Transition of large specialized farms is still expected, as they occupy main part of usable area and could enable a strong reduction in European pesticide consumption.

Introducing more biodiversity in market-gardening cropping systems to reduce pesticide use can be done by (i) cropping a larger number of species, especially with resistance genes, to increase

the mean crop return time of the most frequent species; (ii) reducing the number of species requiring high levels of pesticide use; (iii) introducing commercial or service species with pest control effects, either during the cropping cycle (e.g. allelopathic effects) or when the crop is buried in soil (e.g. biofumigation). Combining these levers with current practices requires therefore a systemic response and a deep redesign of cropping systems (Altieri, 1999; Morel et al., 2020).

Farm ability to adopt agroecological practices depends on technical, economic and socio-political processes; some of which are in farmers' hands, while others depend on other actors from upstream and downstream value chains. Numerous studies were carried on individual factors determining farmers' intention to adopt sustainable practices (belief, personal preferences, resistance to change, etc.). By contrast, the systematic study of the other actors' impacts is scarcer. Aare et al. (2021) consider that "the transitional path toward more sustainable food systems cannot be addressed at farm level alone, but must include changes in the wider food system(s)". These authors identified several barriers encountered by Danish biodynamic farmers for enhancing biodiversity: national and European legislation, markets, knowledge access, and input supply. Crop diversification was studied by Casagrande et al. (2017) and Morel et al. (2020) on a range of crops, and by Boulestreau et al. (2021) on market-gardening. Four characteristics frame the interactions between vegetable farmers and other actors. First, as most crop cycles only last a few months, organizing both multi-annual and infra-annual combinations of vegetable crops increases complexity. Second, vegetable crop rotations enable only short fallow periods for service crops. Third, harvesting date is an important criterion in commercial negotiations. And last, distributors' quality standards are very strict when it comes to visual defects. This is why diversifying crop rotation, although being a promising way to control pests, is so difficult to carry out in market-gardening systems.

The aim of the study was to *identify the current barriers to the mass deployment of diversified rotations devoted to control pest and diseases in market-gardening systems*, which depend on the combination of the various actors' strategies in agri-food systems.

2. Design/Methodology/Approach

System agronomists have long sought to identify the obstacles encountered by farmers when they try to innovate, related to plot characteristics, land or labour force access, knowledge and know-how, etc. (Keating and McCown, 2001). Influence of other stakeholders was more recent studied with for example sociotechnical approaches and multi-level perspective (Gaitán-Cremaschi et al., 2019). Combining agronomic and sociotechnical frameworks enables to take into consideration the complex relationships between upstream chain (mainly genetic selection and input supply), farmers, advisory actors, downstream chain (mainly collection, storage, processing and marketing). Barriers to crop diversification reinforce each other in a systemic way, explaining a systemic lock-in. This was identified on field crops (Vanloqueren and Baret, 2009; Meynard et al., 2018), sugarcane and banana (Della Rossa et al., 2020), and was initiated in vegetable production (Boulestreau et al., 2021). We used the socio-technical inquiry approach (Casagrande et al., Submitted to IFSA symposium) and surveyed different categories of actors likely to hinder the large-scale adoption of diversified crop rotations in market-gardening systems. We started the analysis by surveying farmers, then input suppliers, advisors, vegetable commercial middlemen settled in the territory up to national distributors, to understand how the latter generate or reinforce on-farm obstacles and how they could help to overcome them. After delimiting the system under study (territory, value-chain, problem to be addressed) (i), we mapped the actors involved in the question of crop rotation diversification, based on interviews with key actors and the collection of existing data (ii). Then we

organized empirical surveys to understand the determinants of actors' practices in relation to crop diversification (iii), and characterized the obstacles and levers to the innovation process (iv).

The study was carried out in two major French market-gardening production basins: Provence (around Avignon, 43° 56' 57.541" N 4° 48' 19.901" E) and Roussillon (around Perpignan, 42° 41' 19.173" N 2° 53' 41.4" E). In Provence, the focus was on crop rotations devoted to control telluric pests and diseases, which are a major problem there, and especially root-knot nematodes. 24 semi-structured interviews were carried out in 2021 based on snowball sampling: 6 farmers, 6 cooperatives and shippers, 3 persons working in distribution companies, 4 agri-food processors, the director of a R&D agri-food process network, and 4 agricultural advisers (Michel, 2021). If most actors were located in the study area, a few of them were outside, such as representatives of national distribution companies. In Pyrénées-Orientales, we addressed two Intertwined questions. We carried out an inventory of the major uses of pesticides on vegetables in the area and identified the obstacles and levers to reduce this use, including crop diversification (Bousquet, 2021). We also studied to what extent the commercial channels represent obstacles or levers to crop diversification (Barba, 2021) and to pesticide reduction (Bousquet, 2021; Strand, 2022). We conducted 25 semi-structured interviews in 2020-2021 and 2022. Interviewees were selected based on previous expertise on the territory: 4 farmers, 7 wholesalers, 6 people working in local distribution channels, 7 agricultural advisors and 1 territorial food project animator. The narratives collected in the interviews were first analyzed on each territory separately (Michel, 2021; Bousquet, 2021; Barba, 2021; Strand, 2022) and were then pooled together to map the different types of barriers and assess their genericity in a cross-cutting analysis.

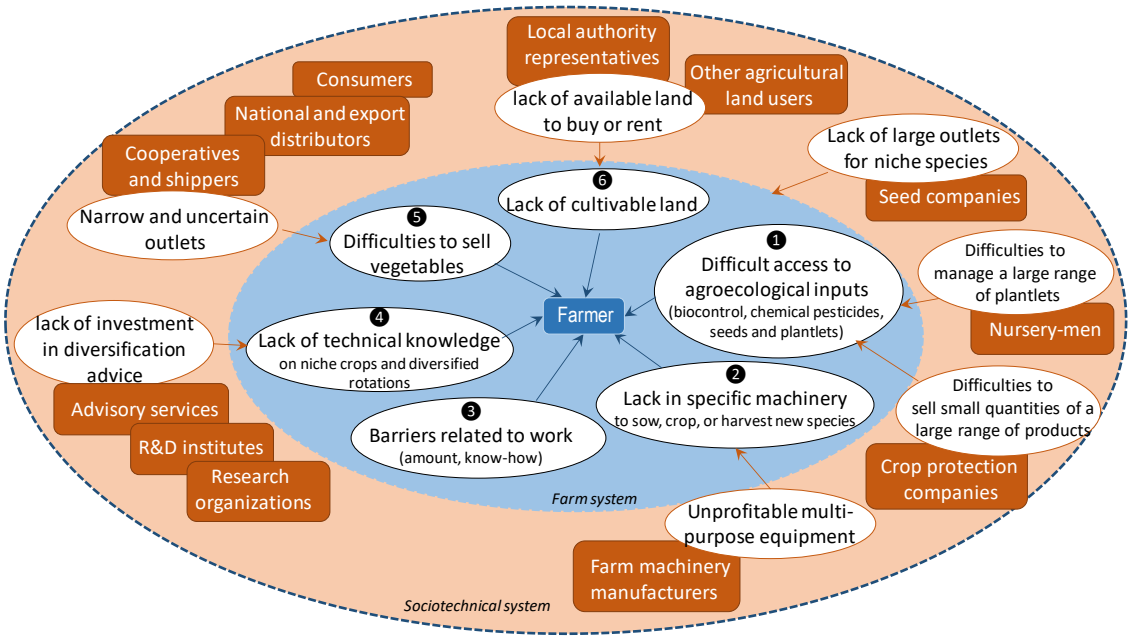
3. Findings

Intuitively, the final decision of crop diversification is first in farmers' hands. This is why we structured results through farmers' barriers and show how they are connected to other actors' barriers. Six categories of barriers were identified based on the two case studies (in the blue oval shape representing the farm system in Fig. 1). The most outstanding result is that most barriers experienced by market-gardeners are linked to barriers experienced by other actors (in the orange oval shape representing the sociotechnical system in Fig. 1), which highlights a sociotechnical lock-in around the diversification of crop rotation for managing plant health.

❶ *Difficult access to agroecological inputs:* several farmers said that high-performance cultivars were lacking for diversification species (e.g., allium spp. against root-knot nematodes). It results in low yields or quality, a lack of profitability and difficulties to find commercial outlets (Cf. ❻). It was linked to seed companies' own barriers which, in the interests of economies of scale, do not develop performing cultivars for niche species due to a lack of large outlets. Methods for plant protection (biocontrol or chemical products for these new crops) were also lacking.

❷ *Lack in specific machinery to sow, crop or harvest new species:* Some farmers were lacking of tools for sowing, planting, harvesting or packaging new species (e.g. a machine for sowing radish, or for bundling stem onions). As these tools are highly specific and these new crops represented a limited acreage on their farms, buying them was not profitable. The difficulty is compounded because, in the study area, there is little sharing of equipment between farmers. In turn, a barrier was experienced by machinery manufacturers, who were not interested in developing multi-purpose equipment due to high investment and low profitability of current limited markets.

Figure 1. Sociotechnical barriers to diversify crop rotations in sheltered vegetable cropping systems to control pest and diseases. Results from the two case studies.



❸ *Barriers related to work:* Farmers noted that diversifying crop rotations increased working time, mental workload, with more small and diverse tasks to coordinate with workers. These barriers are not specific to plant health challenge, but common in crop diversification (Dupré et al., 2017). Contrary to the others barriers, this one was not linked to the constraints of any other specific actor, apart from overall elements relating to labor market, not been investigated in this study (e.g. labor costs, labor regulations, capacity to find and keep skilled workforce).

❹ *Lack of technical knowledge*: surveyed farmers lacked technical references and skills for specific practices (e.g. push-pull practice) and for cultivating niche crops, and on the best way to associate service and cash crops to manage pests. For example, to control root-knot nematodes, trap crops need to be positioned at the period when the mobile larvae are alive, so that they reach trap crop roots. These barriers to technical knowledge are linked to a lack of investment in technical references on crop diversification from advisory services, R&D institutes and research organizations.

❺ *Difficulties to sell the agricultural products coming from diversified crop rotations*: This was a major brake expressed by most interviewed farmers. Numerous marketing barriers exist, but only two are presented here. First, farmers were faced with a lack of outlets for new species. To control pests and diseases, it may require to opt for cropping and harvesting periods that do not correspond to marketing expectations. Cooperatives, wholesalers and distributors built their supply and marketing strategies on economy of scale with large volumes. They are thus reluctant to sell a diversity of vegetable species, each with smaller quantities. Second, some interviewed farmers feared losing their commercial relationships on their main crops and the economic consequences.

❻ *Difficulties in land access for cropping new species*: This barrier is strongly related to the preceding issue ❺. Crop diversification reduces the volume to be marketed per species. Some farmers wished increasing the area to be planted with vegetables, either by internal reorganization between productions or by leasing or purchasing new plots. But they were faced to lack of available

land near their farms and high cost of land in urban green belts. The actors involved in the land access barrier were diverse: other farmers, local residents, local authority representatives.

4. Practical Implications

The analysis shows how the impediments coming from the various actors act altogether in a systemic manner to hamper diversification of crop rotations. First, a farmers' barrier is almost always interdependent with another actor's barrier. Second, farm barriers are often interconnected: if a commercial barrier (e.g. reduction in volumes per species) could be overcome by increasing land area, this option is also hampered by other actors' strategies. To develop such crop rotations to manage plant health, it is therefore mandatory that changes occur not only in farms, but also among all actors also involved in the systemic lock-in. This is tricky because only part of the actors is anchored at a local scale, whereas others (e.g., distributors) escape from the local problem. In an attempt to overcome the impediments observed in this analysis, we later carried out workshops with the main actors engaged in the sociotechnical lock-in to co-design coupled innovations capable to unlock the system. They proposed changes at different levels of the agri-food system that could partly help farmers to diversify their crops, as for example coordination among farmers at the territory level, or between farmers, commercial middlemen and distributors to develop new outlets.

5. Theoretical Implications

Most barriers identified are similar in the two geographical areas and are consistent with findings published in other European countries (Casagrande et al., 2017; Morel et al., 2020). Our results enlarge those obtained by Boulestreau et al. (2021) in one of the two territories studied in this article, and thus gain in genericity. The choice to entry by the farmers' point of view on the lock-in process may have created an asymmetry to understand others actors' points of view. Some actors would merit a deeper understanding, both upstream (machinery companies) and downstream (marketing companies). Another blind spot concerns consumers' eating habits, which also hinder the development of certain vegetables that are difficult to cook or little appreciated.

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SYSTEMIC CHANGE FOR SUSTAINABLE FUTURES
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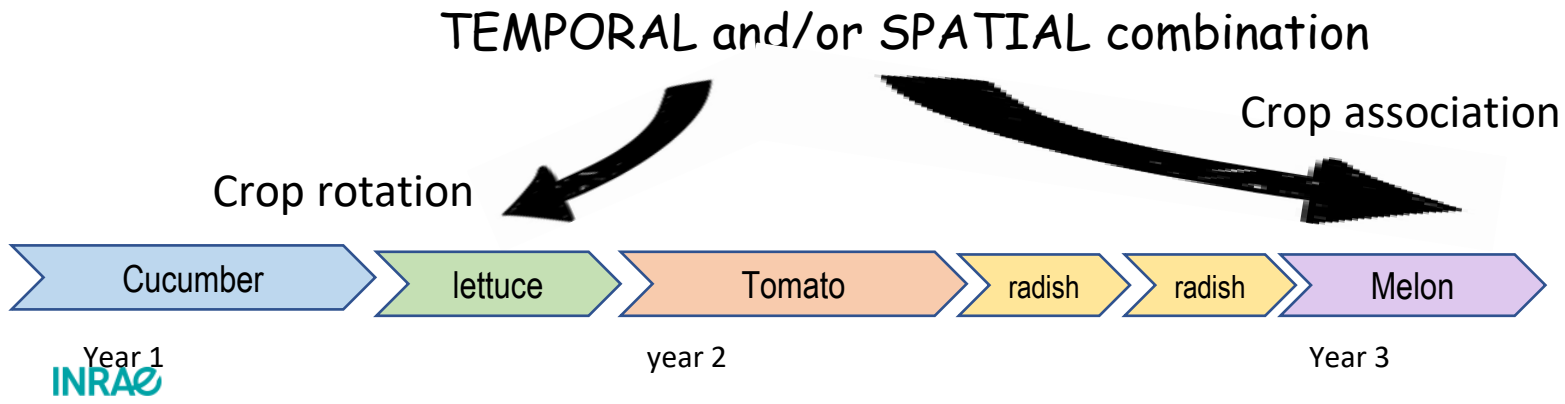
[b] Agroecological vegetable systems Experimental Facility, INRAE, Alénya, France
[c] Université Paris-Saclay, INRAE, AgroParisTech, UMR SAD-APT, 91120, Palaiseau, France

Socio-economic context and state of the art

- Agroecology (AE) : A way to preserve human and environment health
- Crop diversification : a large potential to lower pest and disease damages + other ecosystemic services (Kremen *et al* 2012, Vialatte *et al* 2023)
- Various ways to manage pests and diseases with crop diversification
  - ↗ number of species (introduce resistant or tolerant species/cv)
  - ↘ crop return time of most frequent species
  - Introduce commercial or service species with pest control effects

  (e.g. allelopathic effects, biofumigation)



The process of sociotechnical lock-in

Crop diversification requires a **deep redesign of cropping and farming systems** (Altieri, 1999; Morel et al., 2020)

Farmers face difficulties in changing their practices towards AE

INDIVIDUALS

farmers' motivations

+

SYSTEM

sociotechnical lock-in

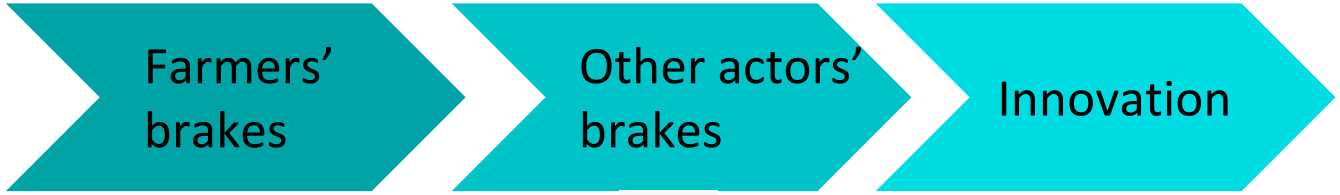
Sociotechnical lock-in (Vanloqueren and Baret 2009, Meynard *et al* 2018, Della Rossa *et al* 2020, Boulestreau *et al* 2021)

Complex relationships between upstream chain, farmers, advisory actors, downstream chain

Each may create a barrier to crop diversification

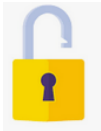
The different barriers to crop diversification **reinforce one another** in a systemic way

From sociotechnical lock-in … to coupled innovation

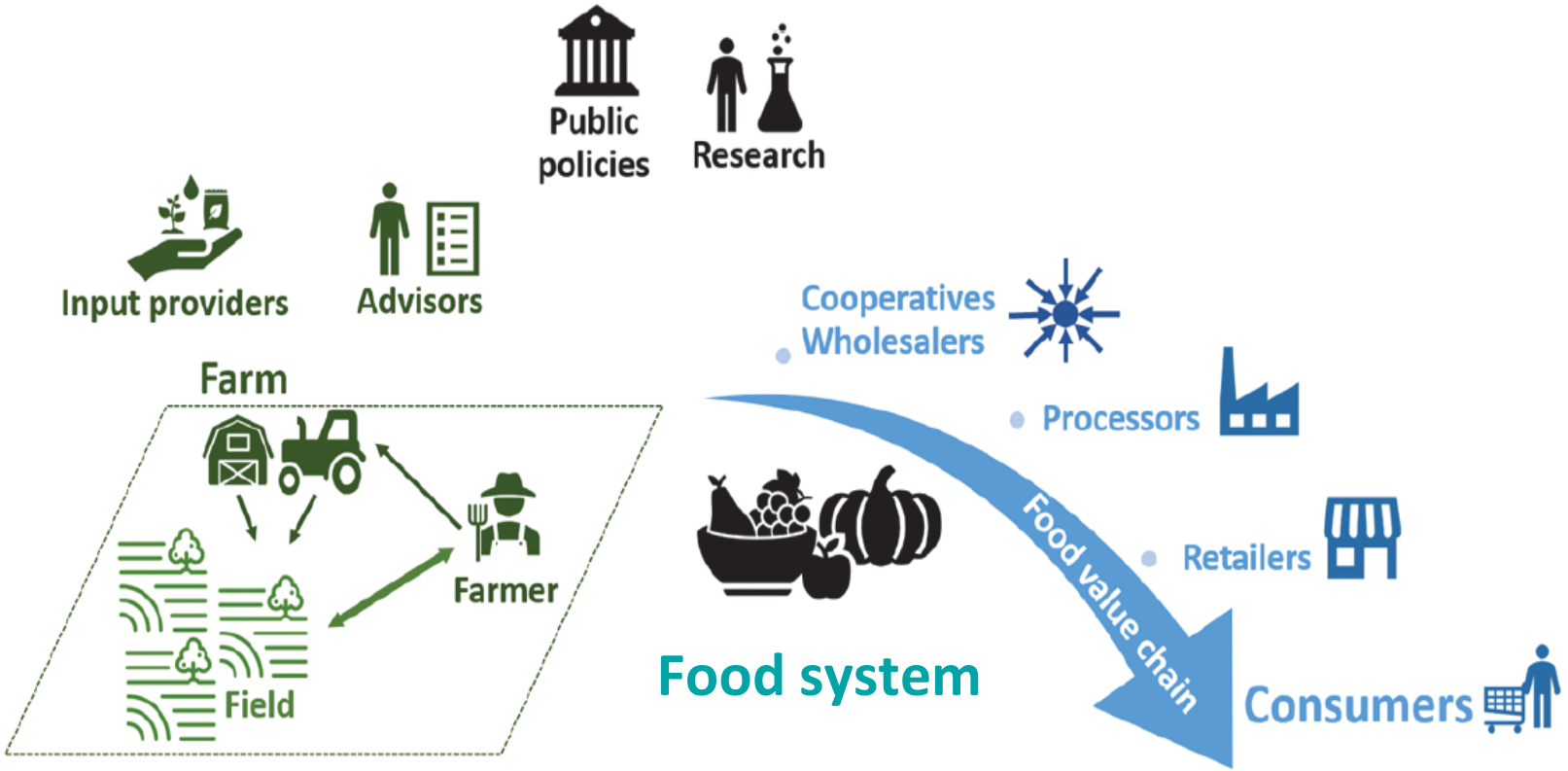


Systemic lock-in

systemic unlocking in agrifood systems



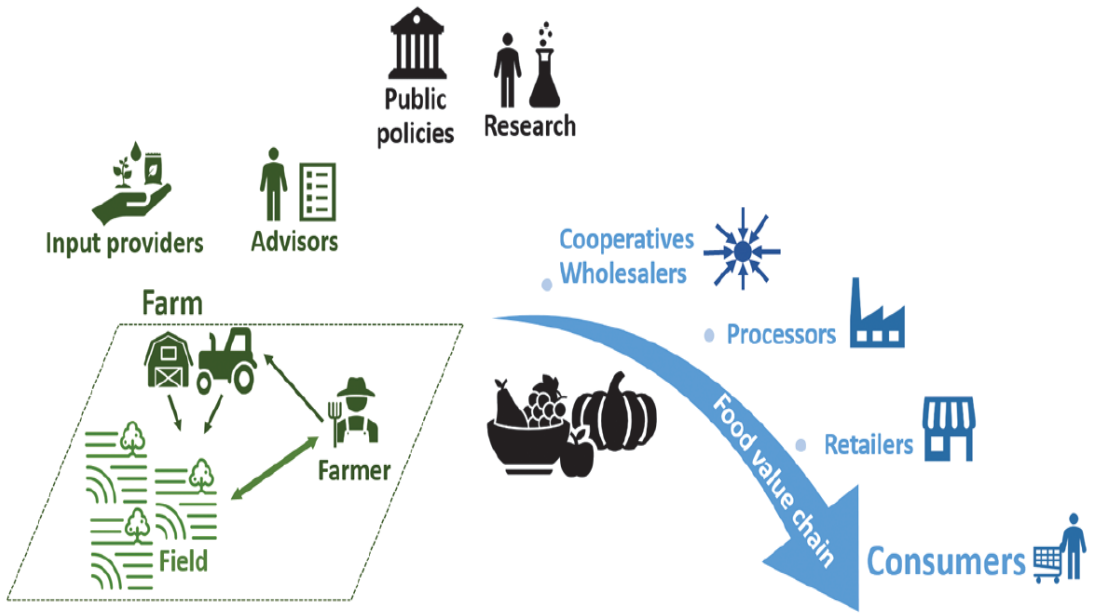
Methods :



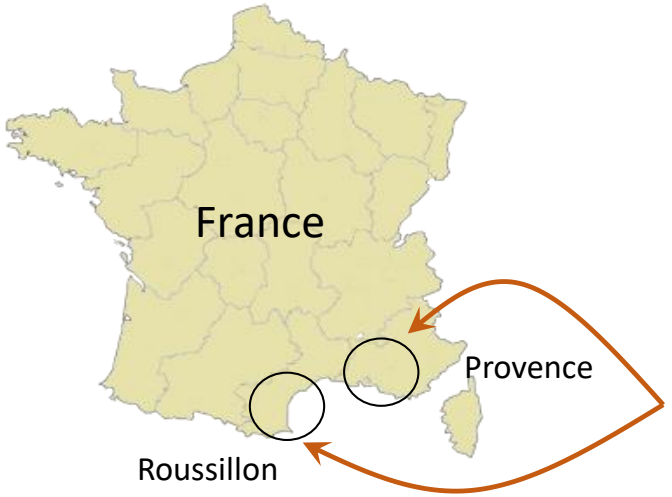
The different categories of actors likely to hinder the adoption of diversified crop rotations in market-gardening systems

Methods : The *SocioTechnical Inquiry Approach* for innovation in agronomy

Developped by Casagrande et al, Theme 3



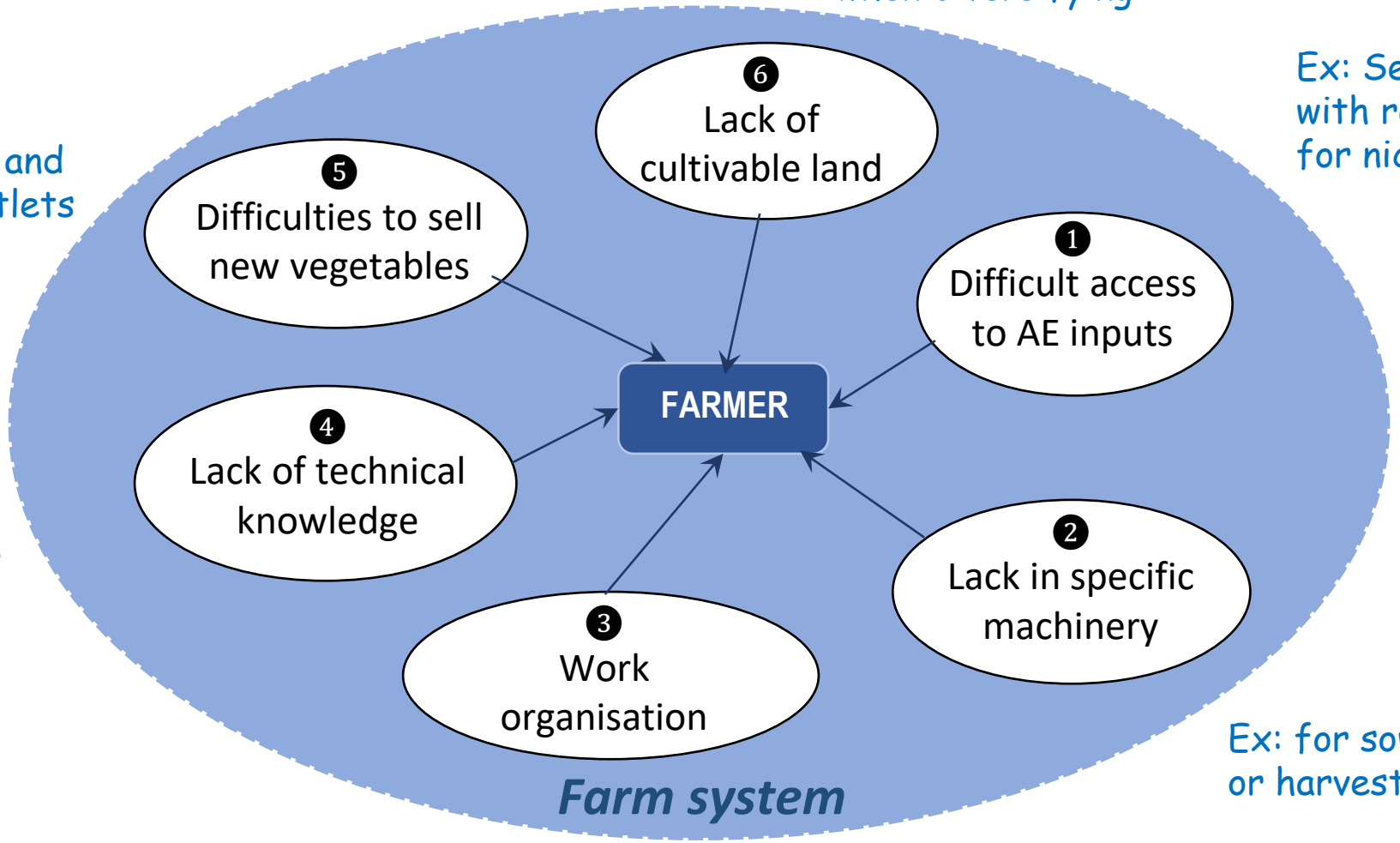
- Mapping the actors concerned by the diversification of crop rotation
- Empirical surveys to understand the determinants of actors' practices in relation to crop diversification (N=49)
- Characterizing the obstacles and levers to the innovation process



2 major market-gardening production basins in France

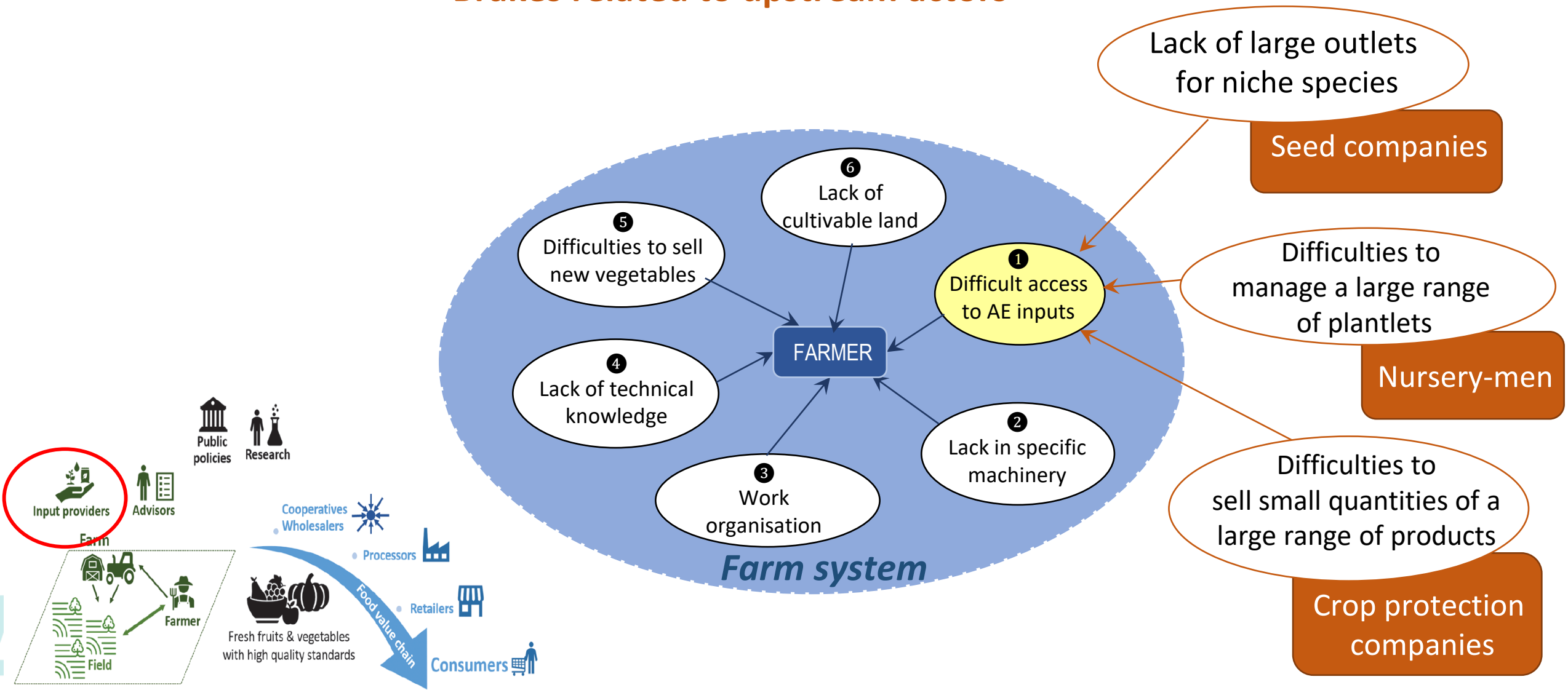
Results : brakes for crop diversification to control pests and diseases

6 categories of brakes related to farmers



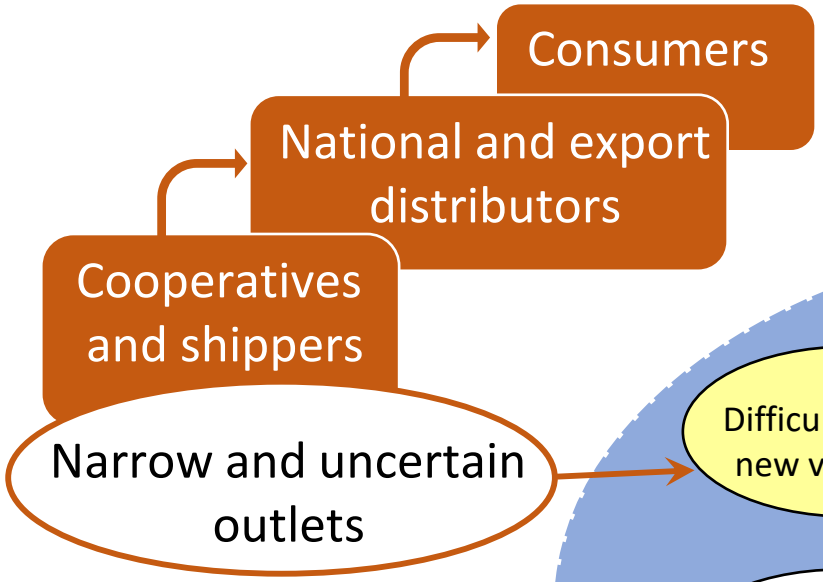
Results : brakes for crop diversification to control pests and diseases

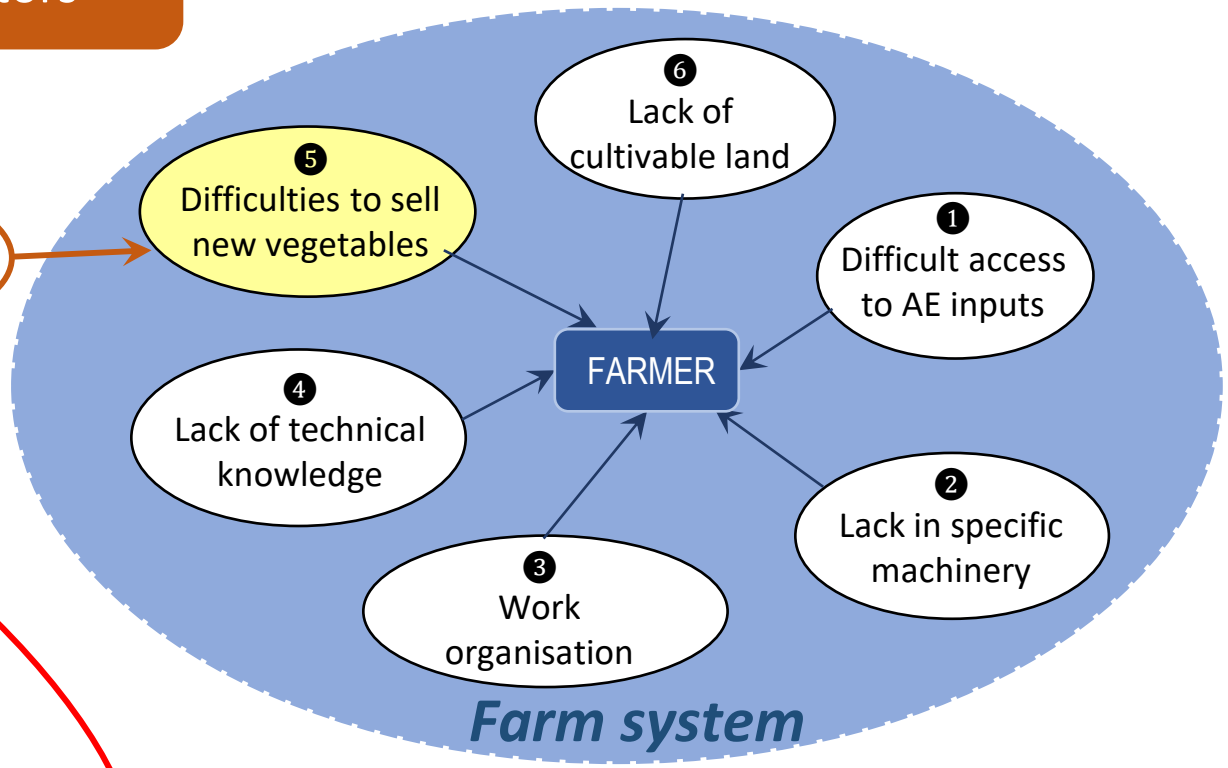
Brakes related to upstream actors

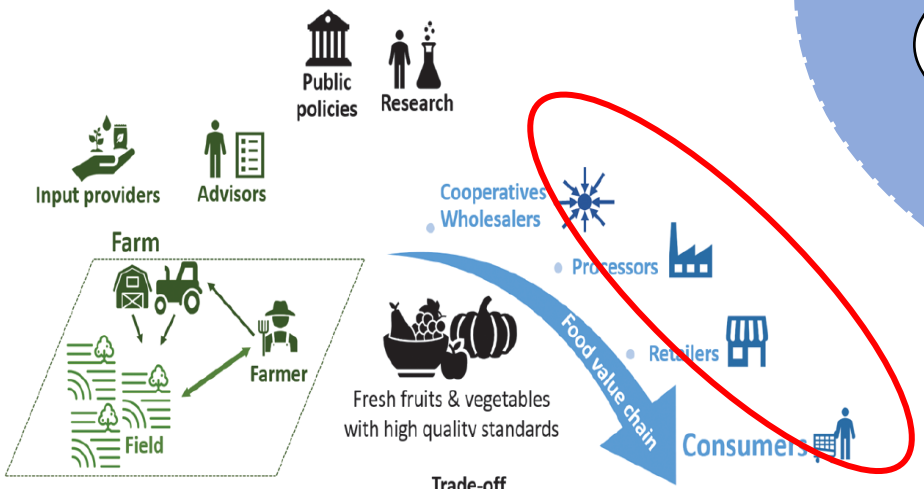


Results : brakes for crop diversification to control pests and diseases

Brakes related to downstream actors

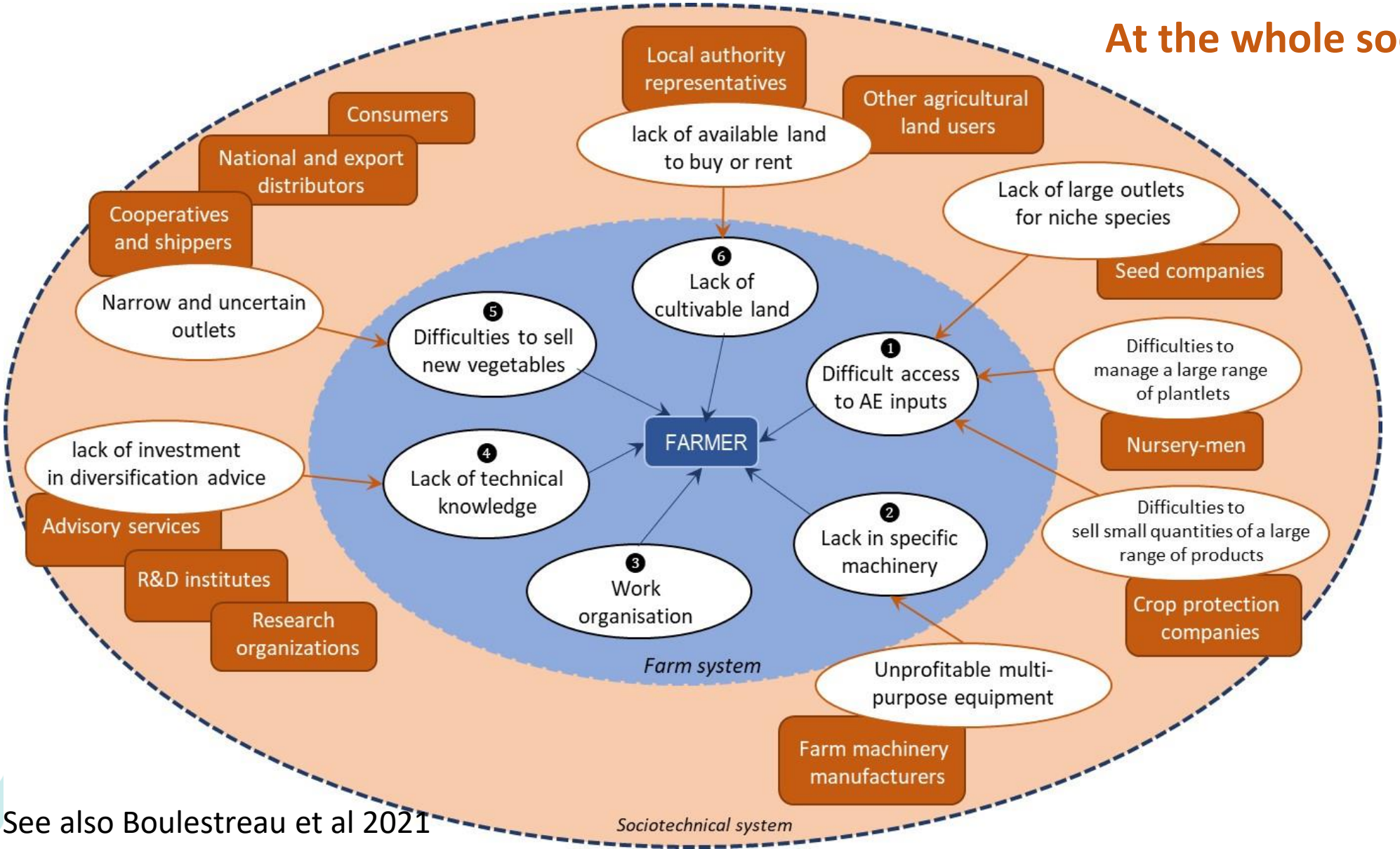






Results : brakes for crop diversification to control pests and diseases

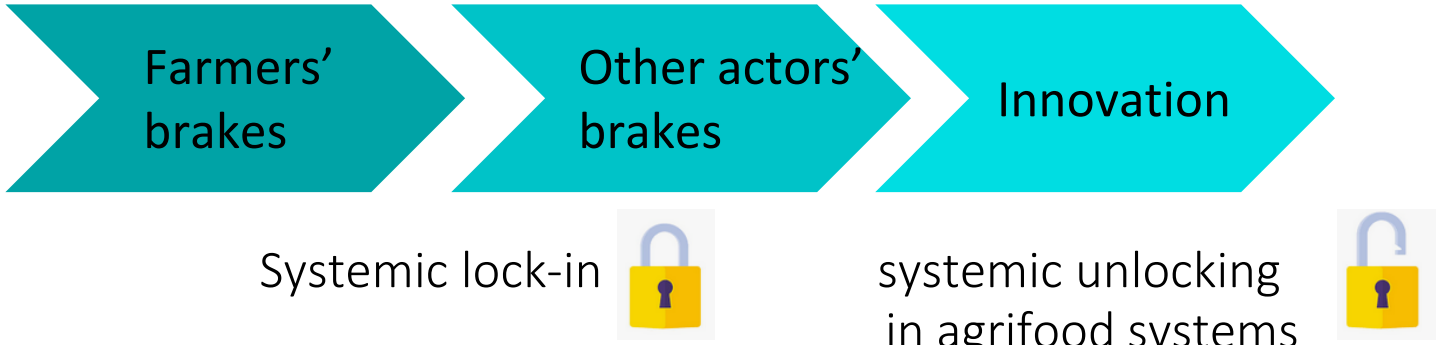
At the whole sociotechnical level system



See also Boulestreau et al 2021

Coupled innovations lock-in (concepts and theory)

From sociotechnical lock-in ... to coupled innovation



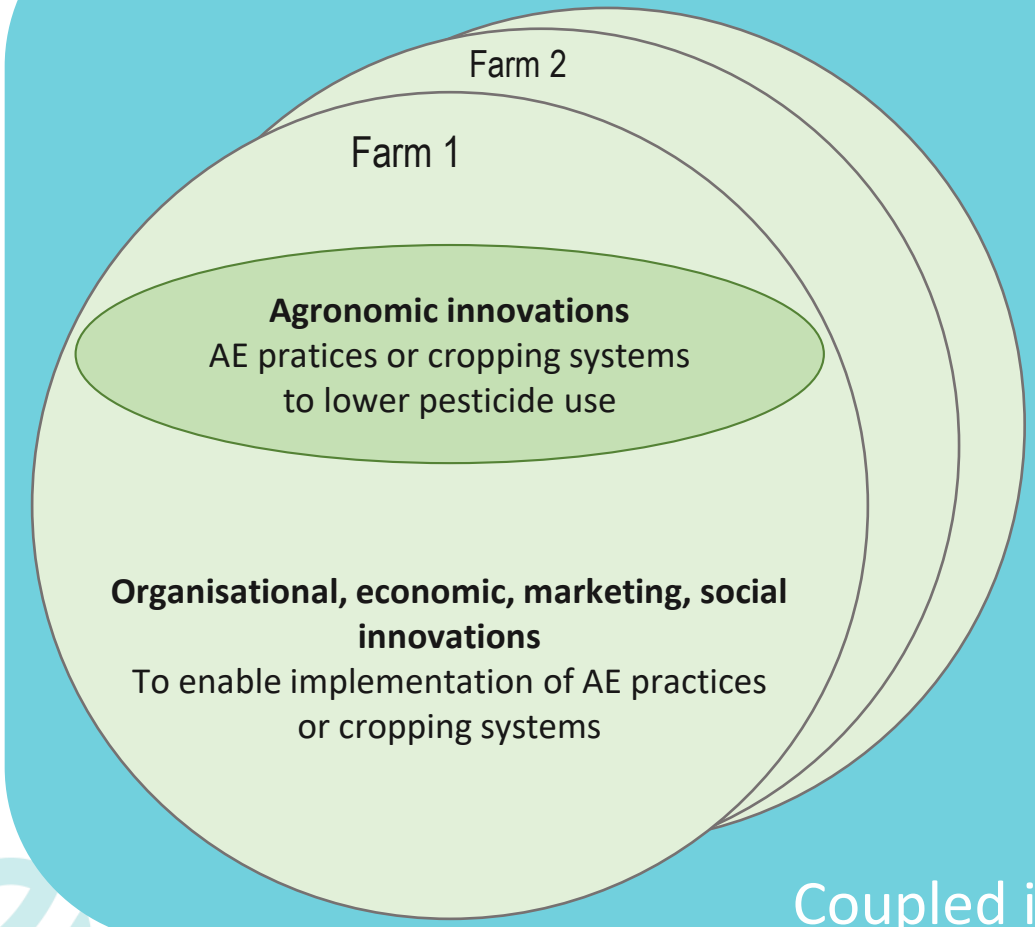
Coupled innovation :

Coordination of innovation processes of different natures (technical, organizational, regulatory, institutional, social), driven by different actors and generally apprehended independently of each other

(Meynard et al. 2017; Boulestreau et al. 2023)

Coupled innovation to support crop diversification : theoretical framework

Innovations on farm



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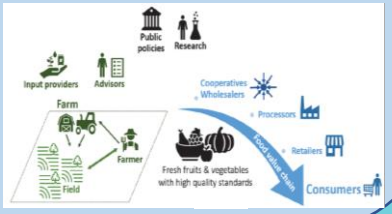
Coordination between food-system actors to favour innovations at farm level

Coordinations

- Between farmers
- Between farmers and upstream/downstream actors
- Within upstream or downstream channels
- With extension services
- With local and national public authorities
- With other production channels

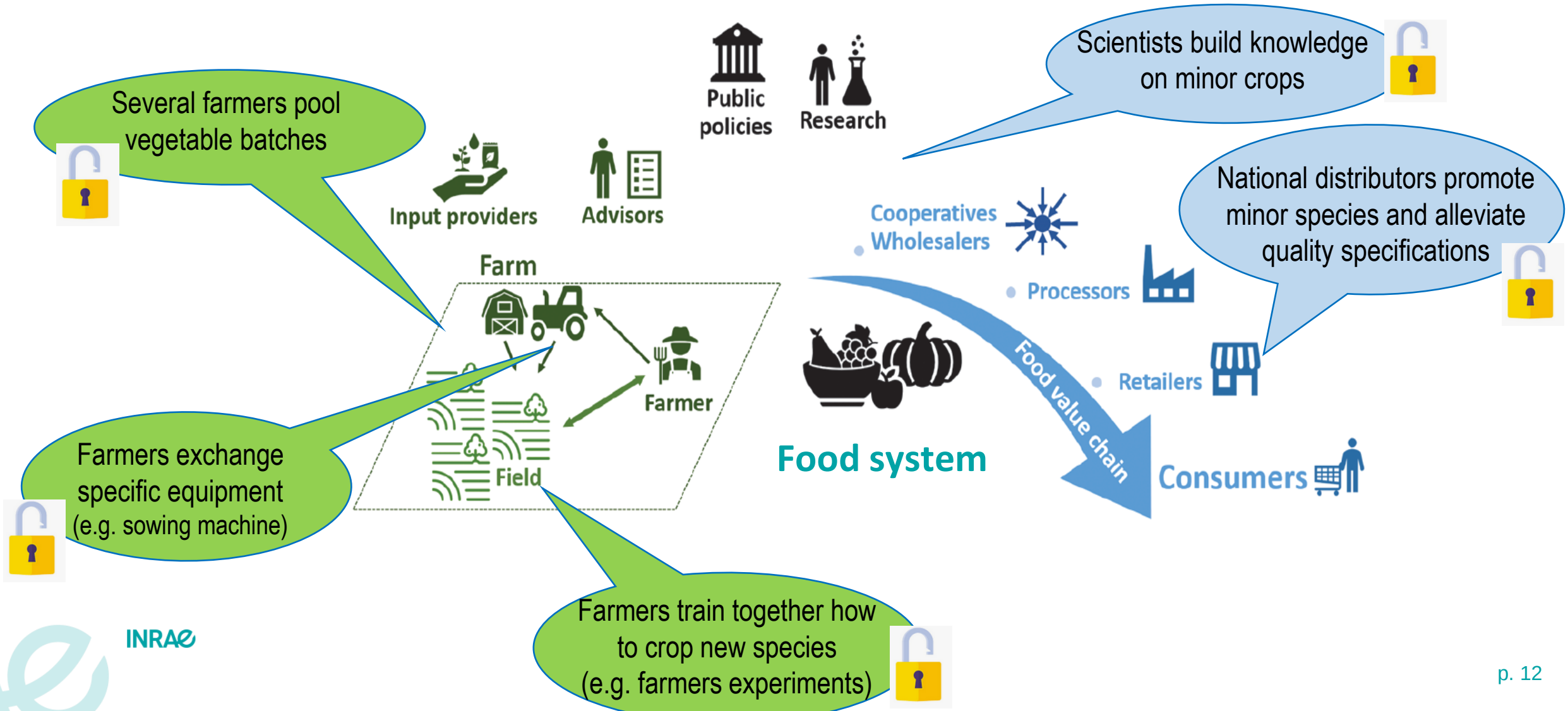


Coupled innovation

AE : agroecological

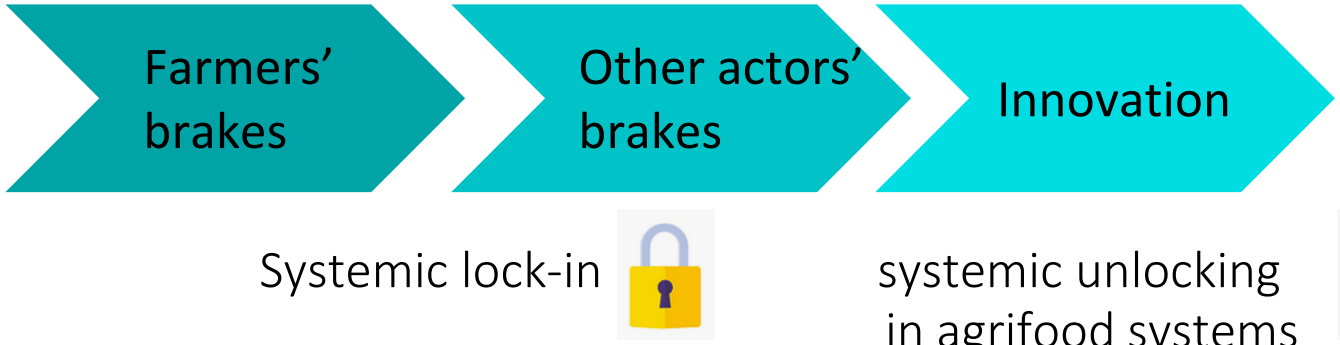
Navarrete et al. submitted

Coupled innovation to support crop diversification : example of a prototype coming from the case study



Conclusion

From sociotechnical lock-in ... to coupled innovation



See also Boulestreau et al 2023

A complex participatory research process driven by scientists

Knowledge gaps (e.g. multi-dimensional assessment of innovations)

How to help stakeholders steer themselves such processes for a massification of change?

Thanks for your attention !

Thanks to all the actors surveyed,
All the participants to the research project INTERLUDE

More information ?

Mireille.Navarrete@inrae.fr
https://ecodeveloppement.paca.hub.inrae.fr/Media/pages_persos/navarrete-mireille

Websites
Ecodeveloppement research Unit : https://ecodeveloppement.paca.hub.inrae.fr
Agroecological vegetable systems Experimental Facility : https://ue-maraichage.isc.inrae.fr/
SAD-APT research unité : https://sadapt.versailles-saclay.hub.inrae.fr/

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