TRAVERSéES: Territorial levers and transition pathways for reducing pesticide use

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Abstract

The TRAVERSéES project aims to identify trajectories for reducing pesticide use by leveraging various territorial tools. To achieve this, we first conducted an analysis of ecological, economic, social, institutional, and individual factors that influence changes in phytosanitary practices. These insights informed the development of a socio-ecosystem model designed to simulate agricultural practice trajectories across territories, which subsequently served as a tool for prospective analysis with stakeholders in the Barrois region (Grand-Est). The project employed a range of methodologies and engaged in a transdisciplinary partnership. This approach led to the emergence of multiple, innovative proposals for territorial transition levers and highlighted the diverse factors considered by farmers, along with varying degrees of sensitivity to these influences.

Keywords: territorial transition levers, agroecosystem modeling, trajectories, participatory modeling, crop diversification, serious game

1. Introduction

Reducing pesticide use in agricultural areas requires joint consideration of the ecological, economic and social components that contribute to this goal (Rebaudo & Dangles 2013; Lescourret et al., 2015). Farmland is a socio-ecological system in where these components are closely interconnected and interact in complex ways (Darnhofer 2010, Gunderson and Holling, 2002). The literature highlights a variety of transition levers that can potentially effect changes in farming practices. These include: (i) ecological levers: such as crop diversification and landscape configuration with regard to crops and semi-natural elements (Tibi et al. 2022), (ii) economic levers: including the costs and benefits of various productions and food value chains (Chabé-Ferret, 2018), (iii) social levers: for example, the impact of training, advice, and the establishment and strengthening of farmer networks (Poppenborg & Koellner, 2014), and (iv) institutional levers: such as CAP subsidies, taxation or product legislation.

With this in mind, the TRAVERSéES project (Ecophyto II Plan, APR 2019 "Territorial levers for reducing the use and risks associated with plant protection products", 2020-2024) aimed to characterise how ecological, economic and social levers activated at the territorial level can initiate behavioural changes associated with a trajectory of reduced pesticide use. To achieve this, the project focused on developing a socio-ecosystem simulation model capable of evaluating the combined effects of these various levers on the ecological and social dynamics of territories, and, ultimately, on stakeholders' practice trajectories

Models integrating the dynamics of the various territorial components are indeed valuable tools for simulating change trajectories (Carpenter et al., 2009). Despite this observation, relatively few such models of this type have been developed to date. In response we have adopted a socio-ecosystem modelling approach that combines ecological, economic and social dynamics. We chose to develop an agent-centred modelling tool, that simulates farmers' treatment behaviours, thereby making it possible to link the dynamics of individual farmer behaviour under the action of different factors, and the trajectories of practices in the territories (Feola and Binder, 2010; Rebaudo and Dangles, 2013). Our goal was to develop a territorial-scale modelling approach that incorporates ecological levers for regulating pests and diseases, combined with economic and social levers to trigger and support the desired transitions.

The work conducted as part of the TRAVERSéES project focuses on the Barrois region as its reference area. This small natural region, located in the Grand-Est region of France, spans approximately 2,500 km^2 between the towns of Troyes, Langres and Saint-Dizier, and encompassing the departments of Aube and Haute-Marne (Figure 1A). It is characterised by shallow limestone soils with intermediate wheat yield potential. Agriculture plays a significant role in the territory (data: CERFRANCE 2017 and RPG 2021, Figure 1B), primarily involving arable farming and mixed farming (the latter being more prevalent in Haute Marne). Additionally, the region features important vineyards in the west (Champagne appellation) along with some vegetables and arboriculture. Conventional farming practices dominate the agricultural landscape.

Historically, the Barrois region has been characterised by mixed farming and livestock rearing (particularly cattle), although this has largely diminished over time. After the Second World War, farming followed the classic trajectory of conventional agriculture, with farms expanding and crop rotations becoming shorter, to intensify production. The "wheat - rape - barley" rotation became the predominant system. Since then, cropping systems have been characterised by relatively low levels crop diversification, associated with two or three crop rotations and large farms that continue to expand. However, in recent years, farmers have been facing problems related to this simplification and to climate change, which are compelling them to change their practices and their farms.

The TRAVERSéES project brought together farmers, agricultural technicians, researchers and concertation engineers to work together on the conceptualisation of the area and the co-construction of scenarios. The aim of this conceptualisation was to characterise the various components of the area and the stakeholders involved in phytosanitary practices. An innovative iterative approach was employed, combining generic tools with the specific features of the Barrois region, along with a participatory modelling methodology. Several stakeholder groups from the Barrois region were partners in the project.

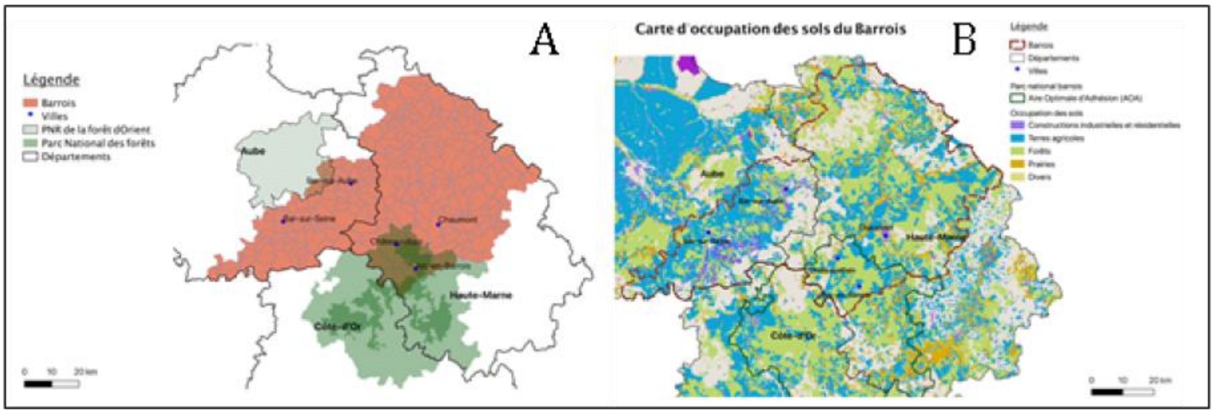


Figure 1: The Barrois region. A: general location; B: land use map

2. Materials and methods

The TRAVERSéES project is structured around four main axes (Figure 2). The primary methods used include surveys, interviews, participatory workshops, serious games and modelling.

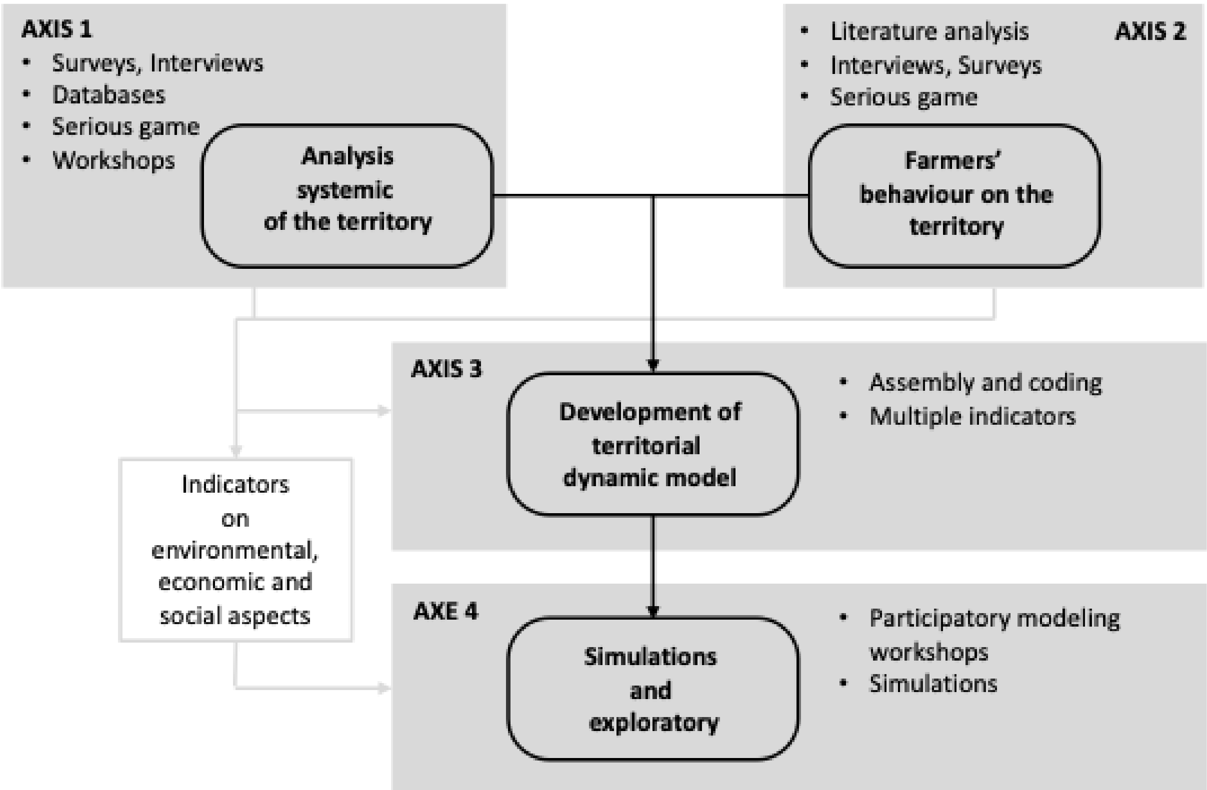
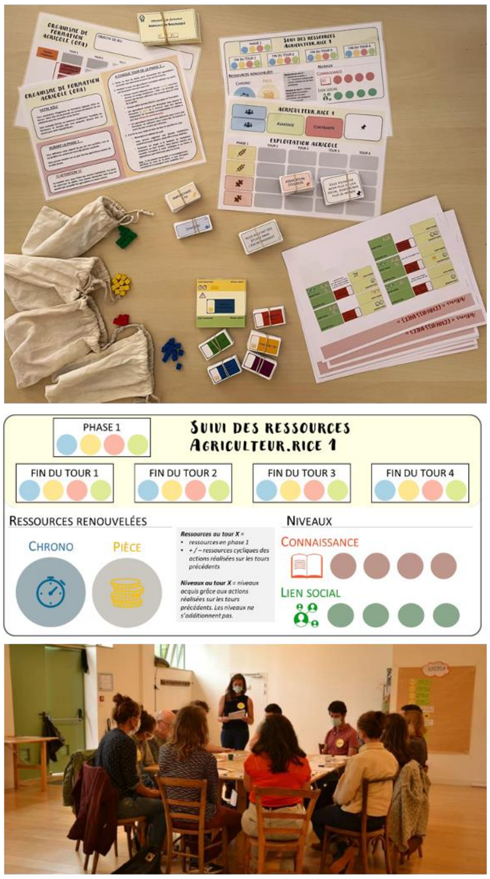


Figure 2: Overview of the four Axes of the TRAVERSéES project and their associated methods

The first axis aimed to identify the ecological, economic and social components of an area that influence agricultural practices, particularly plant protection practices. The methodology included: (1) a literature review examining the links between hedgerow establishment and pest and disease regulation (Précigout and Robert, 2022), (2) an online survey which gathered information from 70 farmers in the Barrois (Honoré 2020, Jacob 2020), focusing on the characterisation of the Barrois and the factors influencing farmers' plant protection practices (the survey was structured into five parts: the farmer, the farm, cropping systems, interaction networks between stakeholders, and phytosanitary practices), (3) interviews with farmers based on the use of cards (playing card format) (Grohens 2021), and (4) the design and use of the "Traversée du Barrois" serious game which involved farmers and agricultural advisors (Grohens 2021).

The serious game "La Traversée du Barrois" is an important component of the TRAVERSéES project (Box 1). It was developed in several stages. Firstly, a series of interviews with farmers insights into the diversity of farms in the Barrois region, as well as the various factors and stakeholders influencing changes in phytosanitary practices. Secondly, the Mété'Eau tool (Barataud et al., 2015; Barataud et al., 2021) was adapted to the TRAVERSéES project. This adaptation resulted in the creation of a set of maps designed to validate the hypotheses derived from the initial interviews on the factors driving change in the Barrois region. Eleven interviews were conducted with farmers using the card game, which served as the foundation for the final game. This serious game was utilized as a tool for exploration and dialogue with farmers and agricultural advisors, focusing on the evolution of farms, the management of change and the relationships among stakeholders. Three serious game sessions brought together stakeholders from the Barrois area.



Serious game: La Traversée du Barrois

Objectives of the game

(1) Identify the components of the Barrois territory
(2) Identify obstacles and levers to farm transformation
(3) Promote dialogue to explore collective trajectories

Concept

The game invovles farmers whose aim is to transform their farms, supported by an Organism of Agricultural Teaching (OAT) providing training courses. Starting from an initial state with objective set at the beginning of the game, farmers must transform their farms by selecting different actions that require different resources (time, money, social network, knowledge).

Initialisation

The game starts with role building. Each farmer establishes their farm and selectes an objective from a range of proposals. These choices determine an initial state of resources.

Flow of the game

During each turn, farmers performs actions, individually or collectively, according to the resources available in order to attain their objectives. The OAT offers training courses to farmers which can help them.

End of the game

The game concludes with a debriefing. Each participant explains the farm they have built, the objective they have set, the strategy they have developed to achieve this objective, and then they give their point of view on the evolution of the use of phytosanitary products throughout the game. Finally, participants are invited to reflect and draw parallels with real-world practices.

Box 1: Presentation of the "Traversée du Barrois" serious game designed and used during the TRAVERSéES project.

The second axis of the project focused on farmers' behaviour regarding their phytosanitary practices. We began by reviewing the literature on the behavioural factors that influence changes in phytosanitary practices (Meunier et al. 2023). Building on this work, we decided to look more closely at three specific processes: farmers' relationship with nature, their perception of risk and their aversion to risk, focusing on how it depends on the type of farming. This was conducted through a new survey of farmers (Da Costa 2023).

The aim of the third axis was to develop a model of the territorial socio-ecosystem and to simulate the trajectories of practices in response to various factors (Bourceret et al. 2024). The model considers spatial scales ranging from the field to the landscape (Figure 3). The model integrates knowledge from axes 1 and 2, and can be used to simulate both ecological dynamics (such as epidemics occurring in fields and the landscape) and social dynamics (farmers' decision-making regarding their farming practices each season), with interaction between the two components: the level of disease influences farmers' profits, which in turn affects their decision to change practices, while the chosen practice also influences the level of disease. The trajectories were analysed using various indicators (calculated both individually for individual farm and at the territorial level) such as the reduction in the level of epidemics, the profits generated by the farms, and the number of phytosanitary treatments applied.

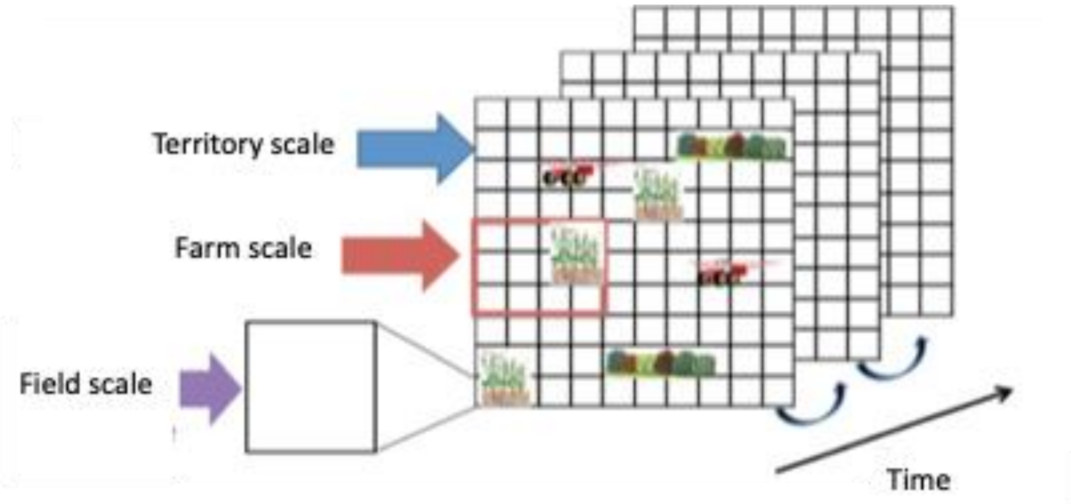


Figure 3: Conceptualisation of the modelled system: schematisation of the scales from field to landscape and the annual and multiannual time scales considered, as well as the ecological (crops and diseases) and social (farmer, neighbour) components taken into account in the model.

The fourth axis of the project focused on utilizing the model to explore scenarios of levers and associated trajectories. Our aim was to work with stakeholders in the Barrois area on the research model produced in axis 3 and to engage discussions on territorial levers and potential trajectories of change. To achieve this, we conducted three successive participatory modelling workshops with farmers and representatives from the OPAs (Figure 4). The aim of the first workshop was to identify the territorial levers that could promote changes in phytosanitary practices. The second workshop focused on calibrating the initial conditions used in the model, to reflect the conditions in the Barrois region, in order to simulate trajectories of change. The third workshop aimed to identify utopian, dystopian and then realistic trajectories for the future of agriculture in the Barrois.

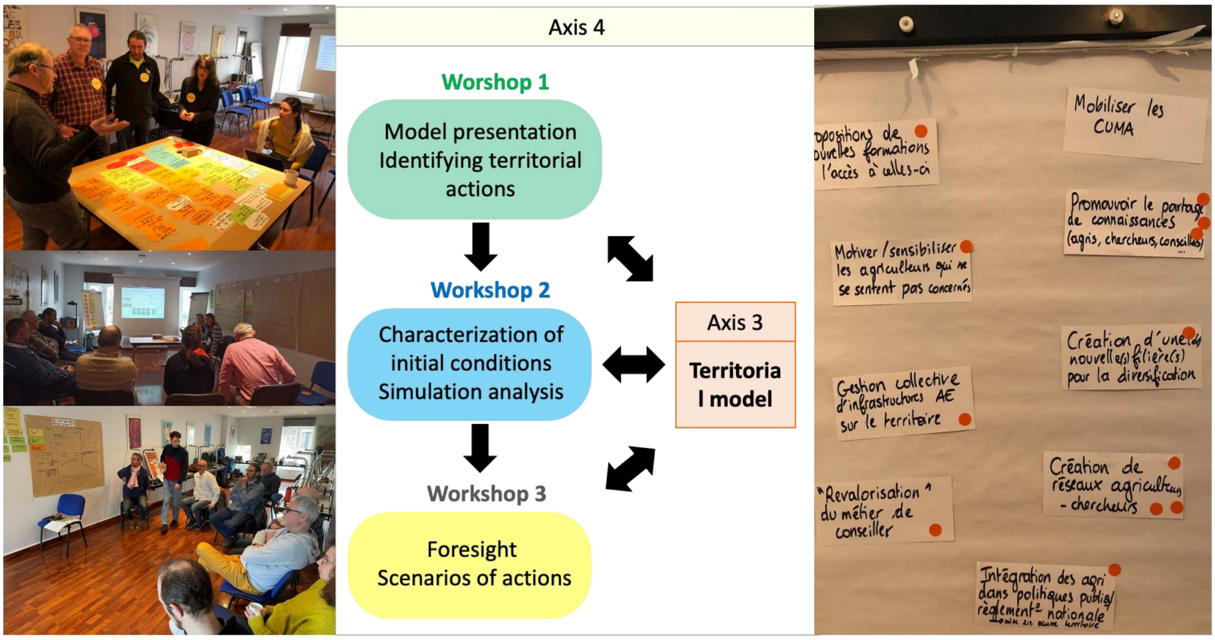


Figure 4: Illustration of the participatory modelling work : The illustration features, at the center, a diagram of the organisation of axis 4 of the project which encompasse the three participatory modelling workshops with farmers and OPAs from the Barrois. On the left: photos from the workshops; on the right: example of collaborative work on identifying territorial levers

3. Results :

The main results of the project are of three types:

3.1 Acquiring knowledge about the functioning of the socio-ecosystem in transition :

- Our work has highlighted the multitude of stakeholders and factors involved in changing crop protection practices in local areas. It appears that farmers discuss about their practices with a diverse range of stakeholders, with various networks of stakeholders operating in the area depending on the practices being discussed (Figure 5). When surveyed about their willingness to change their practices, the majority of farmers expressed a desire to reduce their use of pesticides but indicated that they lacked alternatives (Figure 5). Beyond economic considerations, the challenges identified by farmers in changing their practices include the need for far-reaching transformation, the time required to implement these changes, and the support and information that are sometimes difficult to find. A renewal of farm advisory services is seen as necessary. Additionally, farmers' groups and training courses are seen as significant levers for change (Grossens, 2022).

- Research into farmers' behaviour confirms that their decisions are influenced by various agronomic, economic, cognitive and social factors. A review of the literature indicates that factors such as confidence, attitude to risk, environmental concern, relationship with living organisms, knowledge of alternative and knowledge dissemination, and social influences significantly affect farmers' decision-making (Meunier et al. 2023). Depending on the scale and the stakeholders associated with these factors, they have been classified as external factors, internal factors and social factors. The work carried out with farmers in the Barrois region reveals a wide range of factors taken into account when making decisions on their phytosanitary practices, including health, pollution, economic aspects, training, networks and knowledge (Figure 6). The vast majority of farmers surveyed considered the legislative regulations on plant protection products as restrictive, and also felt that these regulations had little impact on reducing the number of plant protection treatments. In addition to identifying the multiplicity of factors, the research highlights a wide variability in farmers' sensitivity to these factors, both in terms of the types of factors considered and the levels of sensitivity (Figure 6).

Figure 5: Extract from the leaflet sent back to farmers on the results of the survey on the characteristics of farms and practices in the Barrois region (January 2021).

- Understanding the interactions between the inclusion of agroecological infrastructures, pest reduction, pesticide reduction and environmental impacts includes a review of the varied and territory-dependent effects of integrating hedgerows into landscapes (Précigout and Robert 2022). The review highlights the important role of hedgerows in preserving biodiversity, and their potential as a source of beneficials for regulating pests. However, this potential is only realised under specific conditions, such as when the contrast in vegetation structure between the hedgerow and the crop is low (e.g., in orchards) or when the beneficial organisms benefit greatly from the hedgerow's resources (e.g., aphid parasitoids). In subsequent modelling work, we studied the impact of pesticide treatments on the interactions between the ecological regulation of pests by beneficials organisms and the inclusion of agroecological infrastructures within the landscape by simulating the ecotoxicological effects on non-target species (Dahirel, 2022). In the simulations, the deleterious effects on non-target beneficials species modify their seasonal dynamics, consequently affecting their capacity to regulate pests.

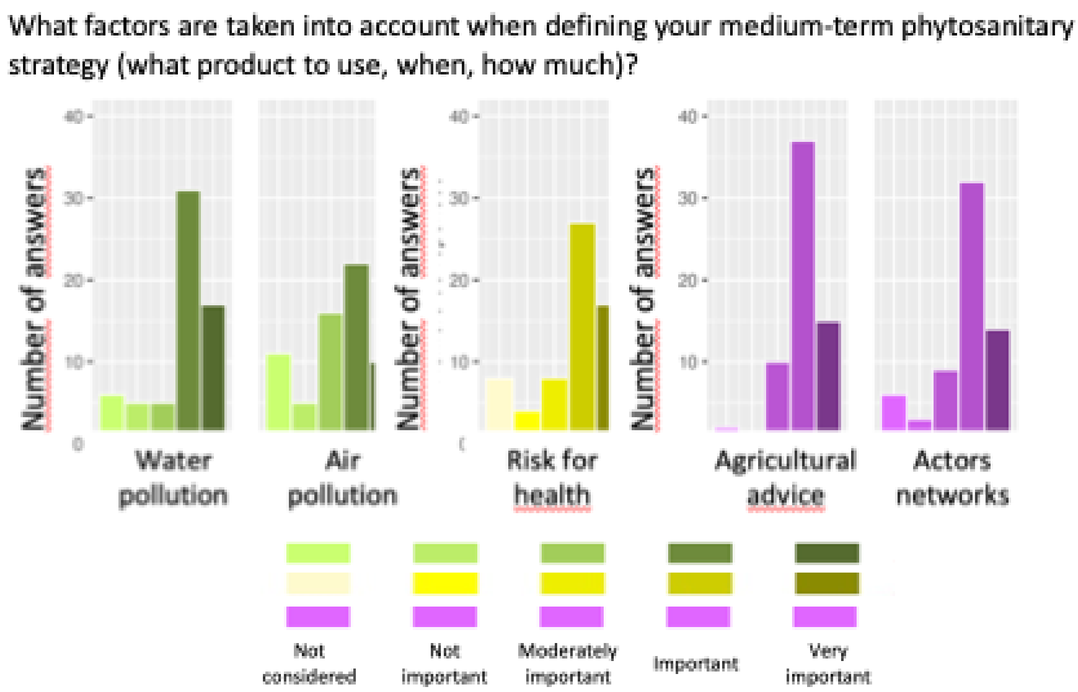


Figure 6: Results of the TRAVERSéES project survey of 70 farmers in the Barrois region (2020) concerning the factors taken into account when defining their phytosanitary strategy. For each of the ten factors proposed, the farmers replied on how they take this factor into account (from "not considered" to "very important").

3.2 Modelling socio-ecosystem trajectories in response to different levers

The knowledge acquired in Axes 1 and 2 has been used to develop a territorial model simulating the trajectories of agricultural practices (Axis 3 of the project). The model simulates, on the one hand, the decisions made annually by each of the farmers in the territory on the practices adopted (taking into account profit, the level of disease and social interactions) and, on the other hand, the dynamics of the disease (taking into account the inoculum, the dispersion of the disease between fields, the use of pesticides and the type of practices employed). We used the model to analyse the impact of various economic (e.g., price of pesticides), ecological (e.g., disease pressure) and agronomic (e.g., effectiveness of alternative practices) characteristics on the trajectories of phytosanitary practices in the simulated area. Preliminary simulations indicate that when the price of pesticides rises, an increasing number of farms transition to pesticide-free practices (Figure 7, first row). Furthermore, we observe that increases in disease pressure, higher pesticide prices, and the effectiveness of agroecological practices all lead to a reduction in conventional practices that rely on pesticides. However, these factors differ in their influence on the trajectories of change (including the speed and form of change) and in the final state reached, which is characterized by varying proportions of types of practice at equilibrium (Figure 7, second row).

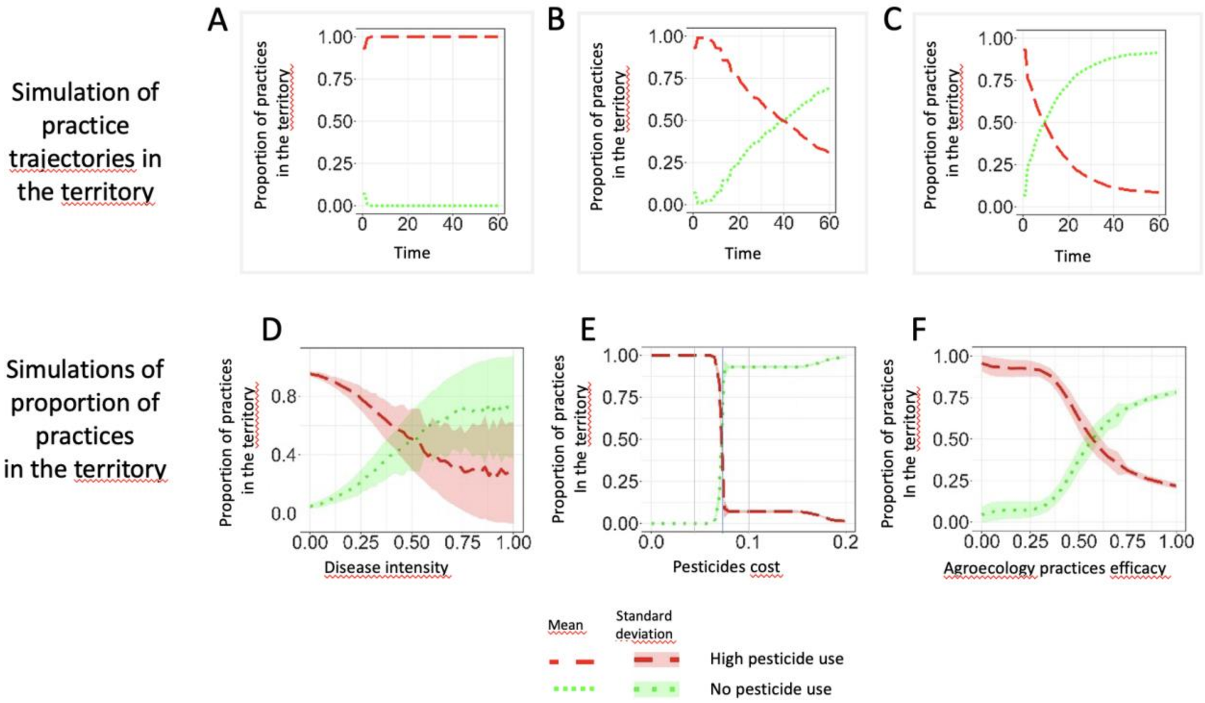


Figure 7: Simulations obtained with the socio-ecological model developed in TRAVERSéES. In red: practices with high pesticide use; in green: practices without pesticides. The first line shows three trajectories of practices over time in an area with three pesticide prices A: low, B: medium, C: high. The second line shows the distribution of simulated practices at equilibrium (when the simulated trajectories have stabilised) as a function of three model parameters (increasing values in y). D: disease intensity, E: cost of pesticides, F: effectiveness of agroecological practices in preventing pests and diseases. An increase in these three parameters leads to a reduction in pesticide use, but with very different dynamics.

3.3 Working with stakeholders on levers and trajectories through participatory modelling

Work was carried out with farmers and agricultural advisors from the Barrois region, utilizing the developed model as a tool for promoting trajectories of change. Three workshops were held during which extensive discussions and collaborative efforts led to the emergence of a variety of original proposals for territorial levers (Figure 4). Numerous levers were proposed during the first workshop. The discussion about their potential impacts underscored the complexity associated with changes in phytosanitary practices. We also note the significance of the region in the discussions and the specific features highlighted around the Barrois region. Some of the levers discussed are more or less specific to a given area, that is, they may be applicable to all regions or tailored to particular localities. The need for exchanges between farmers, the importance of awareness-raising initiatives, fostering conviviality, and the need for changes in training and farm advisory services are some of the key points that emerged.

The second workshop enabled progress to be made in defining farmer profiles, characterised by their practices, levels of knowledge and sensitivities which correspond to the characterisation of an initial state in the Barrois. This workshop also provided an opportunity to discuss the combinations of levers that can effect change in phytosanitary practices, as well as the limitations associated with these actions.

The aim of the third workshop was to collectively identify trajectories for agricultural development in the Barrois region up to 2035. Participants engaged in collective reflection on the levers and realistic actions that could engage a transition towards a "zero phyto" situation. Several levers were proposed, including the enhancement and coordinated implementation of agro-ecological infrastructures. The discussion highlighted the importance of collaboration among a diverse range of stakeholders (such as citizens, consumers, researchers, farmers, trainers, industry players, etc.) in envisioning the future of the region and its agricultural practices. The following specific ideas were put forward: the creation of a "local collective catering" living lab, the creation of a Workshop Zone surrounding the park, collaboration between researchers and farmers in their field, the promotion of local initiatives involving citizens, and the expansion of farmers' collectives. Additionally, the idea of launching a "Barrois gazette" was proposed to centralise ideas related to local practices and initiatives, with the goal of popularising them. The introduction of environmental education in schools (primary, secondary and high schools) was also proposed.

4. Discussion and conclusion

The TRAVERSéES project focused on identifying the factors that influence trajectories to reduce pesticide use in local areas. Our aim was to understand how various types of levers, activated at territorial level, can initiate a process of change in the behaviour of stakeholders. We have traditionally categorized these levers into four types: (i) ecological (factors related to composition, diversification and configuration of the landscape in terms of crops and semi-natural elements), (ii) economic (e.g. aspects such as the costs associated with the use of pesticides, benefits derived from agricultural production, variations in market prices, or product taxation), (iii) social (elements including training available to farmers, agricultural advisory services or the establishment and strengthening of farmers' networks), and (iv) institutional (considerations involving subsidies from the Common Agricultural Policy CAP, taxation or product legislation).

The work carried out with farmers in the Barrois region highlights the numerous factors they take into account when deciding about their plant protection practices, including health, pollution, economics, training, networks and knowledge. A significant majority of farmers perceive legislation regarding plant protection products as both restrictive and having minimal impact on their practices.

In addition to this diversity of factors influencing decisions, there is also a considerable variation in farmers' sensitivity to these factors. These differences in sensitivity suggest the potential crucial role of farmers' individual and cognitive characteristics in influencing farmers' willingness to change their practices, alongside the feasibility of implementing such changes (Meunier et al. 2023, Honoré et al. 2024). Analysis of the survey conducted among farmers in the Barrois region (Honoré, 2020) revealed three distinct sub-populations of farmers, characterised by their overall level of sensitivity to the factors mentioned above (with the exception of economic factors, which were acknowledged as important by almost all those respondents).

The first sub-population, representing a minority, appears to be sensitive to all the identified factors. The second sub-population was not very sensitive. Finally, the third sub-population, which constitutes most respondents, showed intermediate sensitivity to the various factors. These results indicate a "horizontal classification" of sensitivity across different factors (rather than a vertical classification by type of factor). These results lead us to consider two types of levers for promoting agro-ecological trajectories: traditional levers that facilitate the establishment of socio-technical conditions necessary for change (such as economic, knowledge and network levers) and levers that relate to the "cognitive conditions of farmers and their imaginations of change", the two types of levers are intertwined and complementary.

An emerging research perspective is to assess whether these findings are confirmed on a larger sample, and to identify the variability among farmers as well as potential farmer profiles, in relation to their sensitivity to different factors with thoughts on corresponding adapted levers. This approach could be based on economic theory and behavioural studies, including (i) the theory of planned behaviour by Ajzen and Fishbein (1980, 2000), (ii) the value-belief-norm approach by Stern et al. (1999), and (iii) the social cognitive theory of Bandura (1986, 2023), which has been influential in behaviour change programmes in the fields of health and education.

A second perspective concerns the modelling work carried out in the TRAVERSéES project. This work has enabled the development of a socio-ecosystem model that simulates the individual trajectories of farmers in response to ecological, economic and social characteristics of the simulated area. In the future, it would be valuable to enhance the model by considering variations in the sensitivity of farmers and the leverage scenarios considered. Additionally, to improve the ecological component of the model, it would be beneficial to consider several bio-aggressors rather than just one, as well as to include ecological functions beyond disease limitation (such as pollination and natural regulation) in the reasoning for trajectories of change in the territories. The RegHaies project, which investigates ecological regulation in fields adjacent to hedgerows (OFB 2024-2028), has been set up with this goal in mind.

In terms of transfers, the results of the TRAVERSéES project could lead to three types of transfer. Firstly, the 'Traversée du Barrois' serious game could be adapted and implemented in other areas. Secondly, the simulations of the socio-ecosystem model could be used to think about public policy recommendations at a regional level. While the developed model does not claim to serve as a realistic trajectory forecasting tool, it can illuminate trends or interactions that are difficult to predict, which should be considered when implementing various levers. For example, the model revealed a risk of oscillation between different practices if farmers are heavily influenced by their recent yields. Finally, the participatory modelling methodology established during the project could be utilized with different groups of stakeholders in other areas to explore systemic visions for the area, the desired trajectories, and to bring out the collective dynamics within those communities of the area.

In conclusion, the TRAVERSéES project has contributed to the debate surrounding the actions territories can undertake to foster the agro-ecological transition (Lequin et al. 2024). The work suggests that it would be worthwhile for local authorities to promote three types of spaces for local stakeholders: (1) exchanges of information platforms about the area and how it functions, (2) spaces dedicated to meetings, discussions and coordinated action and (3) space for collective opportunities with concerted collective work and shared achievements. By establishing these types of spaces, local authorities can enhance collaboration and support the transition to agro-ecological practices within their communities.

Concerning the "information" aspect, it has become apparent that farmers sometimes lack information about what exists in their area (local resources including characteristics of the area, available innovation, existing networks, practices, agro-ecological infrastructure). Regarding the "meetings" aspect, the aim would be to organise spaces for discussion, conviviality and consultation, with the possibility of creating collective dynamics, while also recognizing that farmers frequently express a lack of time for such activities. In addition to providing information and organising meetings, the area can promote coordinated collective action on specific initiatives, for example setting up a production chain or implementing concerted hedgerow planting or creating farmers' groups to collaboratively co-construct objectives and solutions.

Furthermore, beyond the essential participation of farmers in changing practices, a whole diverse range of stakeholders in the area need to interact to address varying needs and promote innovative coordination and cooperation (Ricci and Méssean, 2015; Dureau, 2020). One approach would be to identify which stakeholders could be involved depending on the specific objectives sought. In this context, Lequin et al (2024) propose a typology of levers implemented at the territorial level and conclude that it is necessary to reflect on the "construction of a territorial policy that feels empowered to initiate more transversality and systemic approaches with the aim of involving a diversity of actors by reflecting on the roles for each, the cooperation processes, and the possible shared visions".

Ethics

The authors declare that the experiments were carried out in compliance with the applicable national regulations.

Declaration on the availability of data and models

The data supporting the results presented in this article are available on request from the author of the article.

Declaration on Generative Artificial Intelligence and Assisted Technologies

Artificial Intelligence in the writing process.
The authors used artificial intelligence in the translation process from French to English

Declaration of interest
The authors declare that they do not work for, advise, own shares in, or receive funds from any organisation that could benefit from this article, and declare no affiliation other than those listed at the beginning of the article.

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