Redesigning cropping systems to encourage the spread of biosolutions

Marion Triolet, Sophie Slezack-Deschaumes, Gaelle Charlier, Guillemette Jeanneteau, Isaac Plaisant, Pascaline Pierson

Agronomic Innovations 91 (2024), 17-27

Redesigning cropping systems to encourage the spread of biosolutions

Marion TRIOLET[1], Sophie SLEZACK-DESCHAUMES[1], Gaelle CHARLIER[2], Guillemette JEANNETEAU[2], Isaac PLAISANT[2], Pascaline PIERSON[3]

[1] University of Lorraine, INRAE, LAE, 54000 Nancy, France

[2] Université de Lorraine, Ecole Nationale Supérieure d'Agronomie et des Industries Alimentaires, Spécialisation de troisième année Protection des Cultures, 54000 Nancy, France

[3] ARVALIS, 55160 Saint Hilaire en Woëvre, France

Correspondence : sophie.slezack@univ-lorraine.fr

Biosolutions, which include biocontrol solutions, biostimulants and biofertilizers, are considered as levers of interest to help with the agroecological transition of farming systems and to improve their resilience in the face of climate change. However, a number of technical and socio-economical gaps still hamper the use of these biological inputs, particularly in arable farming systems. The aim of the workshop was to consider the conditions that would facilitate the integration of biosolutions into cropping systems and to identify the relevant indicators to be considered to ensure their widespread adoption. It has emerged that while biosolutions are considered as innovative solutions, they have complex modes of action. The challenge is to identify the best conditions that make biosolutions effective, based on field experiments such as the one carried out at the ARVALIS experimental station in Saint Hilaire en Woëvre, France. The effectiveness of these solutions, a key determinant of their adoption, depends on their rational use in combination with other agro-ecological levers. It has also became clear that if these solutions are to be adopted on a large scale, the evaluation of systems including biosolutions must not be based solely on productivity indicators, but must also take into account all the 'co-benefits' associated with these solutions (multi-performance concept).

Keywords : biosolutions, farming systems, agroecological transition, landscape, multi-performance.

1. Introduction

Developments in agricultural practices since the beginning of the 20th century have been characterised by the implementation of new technical solutions such as synthetic inputs. These innovations have made possible to control factors limiting crop production and thus guarantee food security. However, these developments have had impacts on natural resources, environment and human health that are now well documented and need to be taken into account when rethinking production models. So the challenge is to maintain and even increase agricultural production, but in a more sustainable by preserving natural resources, and by improving the resilience of agricultural systems to climate change.

One way to achieve this objective is through the agro-ecological transition, which should enable innovative and economically resilient cropping systems to be designed. The aim here is to produce by strengthening the functional interactions and biological processes that underpin ecosystem services in agro-ecosystems rather than relying on external inputs.

In the transition gradient (Thérond et al., 2017), the first level is to at least partially substitute external inputs with bio-inputs or biosolutions. Bio-inputs are biological solutions (macro- and micro-organisms, substances extracted or derived from living organisms) used to ensure agricultural production, including 'biocontrol' products, 'biostimulants' and 'biofertilisers'. By extension, bio-inputs are also solutions that can be used in animal health. There are high expectations of these solutions, which are seen by public policy as major levers for ensuring the transition. However, because of their intrinsic nature, these solutions suffer from a number of 'weaknesses' (in terms of supply, effectiveness, profitability and acceptability) which are holding back their democratisation, or even jeopardising them. We therefore also need to rethink our approach to the use of these innovative inputs to facilitate their integration into cropping systems.

The objectives were therefore to discuss about :

1/ the contribution of biosolution innovations to the agro-ecological transition?

2/ the conditions for integrating biosolutions into cropping systems?

3/ the indicators needed to ensure the adoption of biosolutions at the scale of food systems?

The discussions were conducted within the framework of a cooperative workshop (“world café”) to facilitate the sharing of knowledge and experience. The workshop was introduced by presenting an innovative experiment in the use of biosolutions, implemented at the ARVALIS experimental station at Saint Hilaire en Woëvre. Located Lorraine region, this experimental station is representative of the mixed crop-livestock farms in its area in terms of its structure and production facilities (130 hectares, 63 hectares of arable crops and 67 hectares of permanent grassland, a herd of 50 Charolais suckler cows on a farrow-to-finish system, and a 180-place bull fattening facility). The station has been involved in an agro-ecological transition process for over 5 years, with biosolutions being one of the tools used. Biosolutions are used to maintain performance by combining levers and changing the scale of assessment.

Three groups of around ten people were then formed and took it in turns to spend 20 minutes discussing the three questions structuring the workshop. The discussions were led by a pair of ENSAIA students and a professional. At the end of the 3 rounds of dialogue, a summary of the contributions was drawn up and presented to the group.

2. How can biosolutions contribute to the agro-ecological transition in arable farming?

2.1. What role can biosolutions play in the agro-ecological transition of farms?

The participants were questioned about the contribution of biosolutions as innovations to the agro-ecological transition of arable farming. responses validated both the innovative status of biosolutions and their contribution to an agro-ecological transition in its three dimensions (practices, social movement, scientific field - Wezel et al 2009). In terms of farming practices, participants argued that biosolutions can reduce dependence on chemical inputs, optimize resources utilization and promote natural regulation.. However to use biosolutions efficiently, it requires us to move away from a simple 'product' approach and to understand the environment and its interactions, thereby changing the decision-making cursors, with their modes of action constituting a very diverse set of solutions. This point has been developed in particular, based on the observation that although biosolutions are not always completely exploratory, they always at least lead to a change in implementation. They require a more systemic approach based on the combination of different agro-ecological levers and the evaluation of these combined effects. The fact that they increase natural regulation through pre-existing processes was also highlighted, making use of assets naturally present in the environment. Biosolutions were considered innovative for the agro-ecological transition as a scientific field because they challenge research to optimise solutions that exist in nature, thus developing a notion of acquiring control over a natural solution (the idea of "domesticating" natural solutions). Their adoption also requires in-depth knowledge of the processes involved, as well as indirect support through the demonstration of functions that can be promoted. Lastly, they have been judged to be innovative for the agro-ecological transition as a social movement, in that they demand a high level of technical and intellectual standards. They require a systemic and precise vision of an ecosystem. In this sense, they lead to the necessary development of new skills, which can be imagined collectively. They also open up the possibility of sharing learning and transferring the knowledge acquired. Farmers can thus play a direct role in improving usage through active participation in Livings lab or On

Farm Experiment-type schemes. A final strong argument developed was the societal recognition that the use of these biosolutions undeniably brings, *subject* however to the implementation of recognition mechanisms with the end consumer (Francis, 2003). The session concluded with a discussion of the fact that these biosolutions cannot be incorporated into systems that have not been redesigned (systems as designed in the context of the use of synthetic inputs). If they are to be used, an indirect approach must be adopted to maintain potential by i) first reducing the pressure exerted by bio-aggressors by promoting prophylaxis, thereby moving from a logic of eradication to a logic of balance (in the case of biocontrols), ii) maximising the supply of mineral elements from the soil, the use of other sources of mineral elements (atmospheric nitrogen) and the uptake of elements by cultivated plants (biofertilisers and biostimulants).

Biosolutions, by forcing those involved in consultancy to move away from the simplistic logic that there is a solution to every problem, are initiating an initial shift towards more complex tactical decision-making, which could lead to other more profound, strategic decisions on a systemic scale.

Even though they are inherent to the development of agro-ecology and should therefore be accepted as a prerequisite, the complexity of implementing them has been identified as an obstacle to the rapid transfer of their use on a large scale. In order to overcome this resistance to change, there is a need to demonstrate their performance in the field, in particular by developing an approach based on successful experience.

2.2 Innovative local experience in the use of biosolutions: the case of the ARVALIS experimental station at Saint Hilaire en Woëvre

The ARVALIS experimental station at Saint Hilaire en Woëvre is being used as a proof of concept.

Following design workshops carried out in 2017 and 2018, the project has embarked on a process of agro-ecological transition, and is intended to serve as a basis for reflection, but not as a demonstration of exemplarity.

In addition to the strict approach to cropping systems (Meynard, 2008), the ideas put forward in the workshops have enabled proposals of the [function; solution] type to emerge (notion of a library of ideas), making it possible to assemble a new production system that meets the objective set (Fortun-Lamothe and Thénard, 2015). The agro-ecological levers implemented are enriched by this complementarity between workshops, bearing in mind that the notion of synergy between crops and livestock can go beyond the closed framework of the farm (Meynard, 2012).

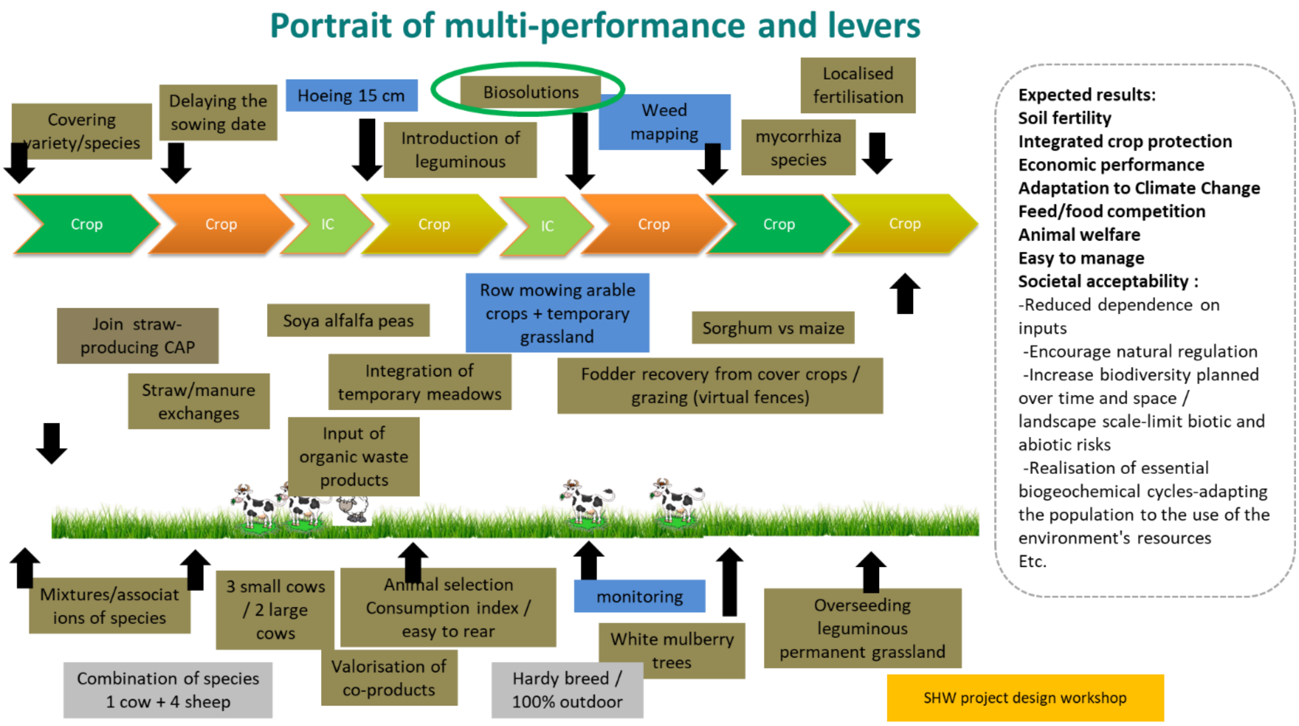

Figure 1: Fishbone representation of the main levers used in arable and livestock farming.

Biosolutions are part of the agro-ecological transition toolbox implemented in this use case. In the lessons learnt, it was agreed that they must be combined with other major levers such as changes in rotation or the use of genetic innovations in the choice of varieties (concept of redesigned system = systems where practices have been modified to maximise the effects of biosolutions while maintaining performance).

Their use also requires us to move away from the traditional approach of assessing the crop on an annual scale using direct indicators of productivity (yield) or quality (protein content). Using them also means daring to change the method and scale of evaluation. Not only does it appear essential to reposition the plot within its cropping system in order to take advantage of temporal effects and combinations of levers at this scale, but it is also essential to identify new indicators that are relevant to the achievement of new objectives (Figure 1). In the example shown, it is demonstrated that an evaluation of biosolutions using a methodology similar to that for chemical protection or mineral fertilisation solutions is rarely to the advantage of these solutions. Compared with chemical reference solutions, it is often difficult to demonstrate a significant effect of biosolutions on indicators such as yield in year n on a given plot. As a result, consideration has been given to the use of other performance markers, for example linked to the biological fertility of soils (spade tests, berkan test, slake test, BMC, etc.), which are more likely to demonstrate the effect of repeated use of biostimulants. Working on the scale of the cropping system provides a more indirect but smoother assessment. The final result incorporates the effect of a combination of levers, as well as a variety of climatic conditions.

On an even more ambitious scale, the example of Saint Hilaire provides an insight into the impact of the use of these biosolutions on a key aspect of agro-ecology - biodiversity - by placing the farm within its landscape. After a first stage of landscape diagnosis, which consisted of identifying all the semi-natural features of interest to flying auxiliaries within a radius of 1 km around the farm's plots, the question arose of exploring more qualitative indicators to assess its attractiveness to these crop auxiliaries with a view to regulating bio-aggressors in agricultural plots.

The DEXI ARENA tool (Figure 2) was used for this purpose. DEXI ARENA was designed on the basis of the multi-criteria decision tree proposed as part of the CASDAR ARENA project. Once the user has entered the various criteria relating to the environment of his agricultural plot and cropping system, the aim is to deliver a score corresponding to the plot's potential for regulating beneficial insects (scores from 0 to 6, plots very unfavourable to very favourable for beneficial insects). This indicator, which has a predictive effect, demonstrated the good potential of the farm's plots using biosolutions to attract beneficials, with an overall score of 5, thus demonstrating the possible service provided by biosolutions in terms of functional biodiversity.

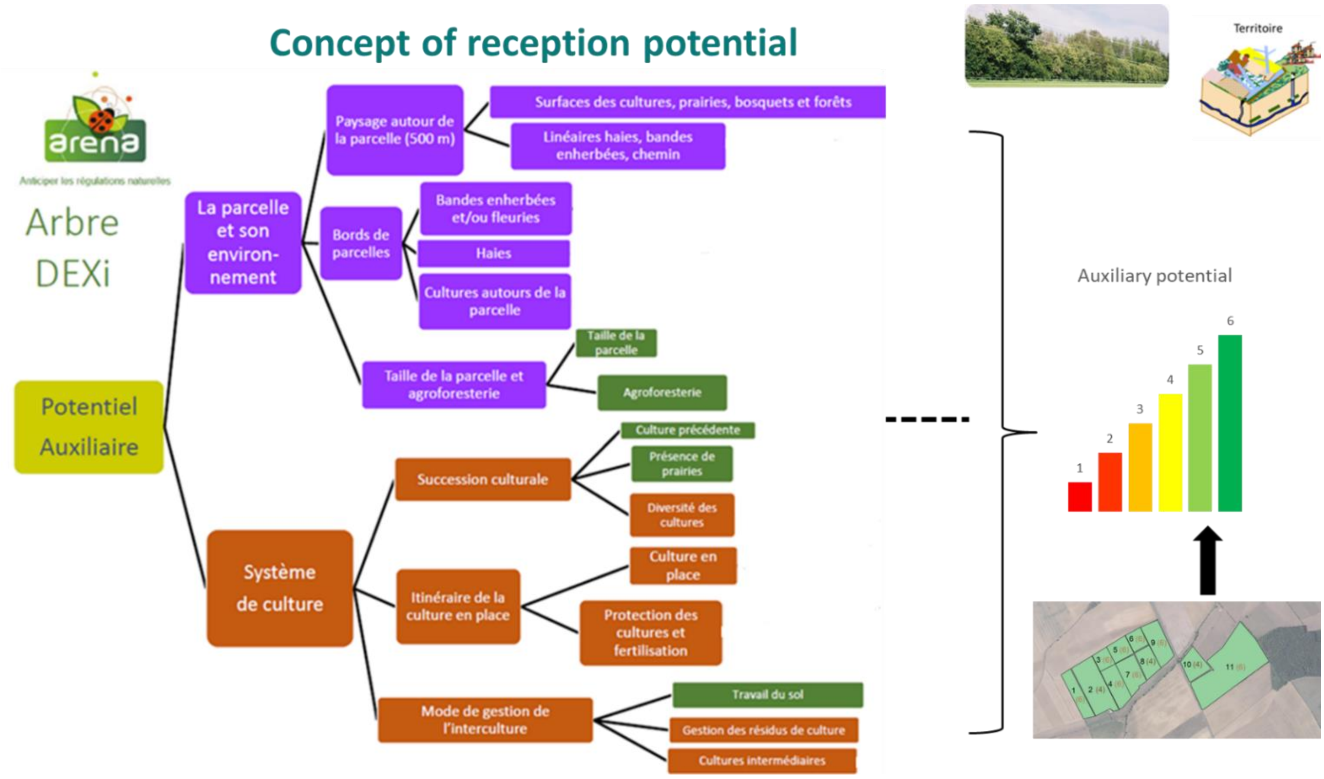

Figure 2: Architecture of the DEXI ARENA tool
Potentiel auxiliaire / Ausiliary potential ; Parcelle et son environnement / Plot and its surrounding environment ; paysage autour de la parcelle (500m) / Landscape around the plot (500m) ; surfaces des cultures, prairies, bosquets et forêts / areas of crops, meadows, copses and forests; linéraires haies, bandes enherbées, chemins / linear edges, grassed strips, ways; cultures autour de la parcelle / crops around the plot ; taille de la parcelle et agroforesterie / size of the plot an agroforestry ; système de culture / cropping system; succession culturale / crop succession; culture précédente / previous crop ; presence de prairies / presence of grassland ; diversité des cultures / crop diversity ; itinéraire des cultures / crop management / cultures en place / established crop ; protection des cultures et fertilisation / crop protection and fertilization ; mode de gestion de l'interculture / intercropping management ; travail du sol / tillage ; gestion des résidus de culture / crop residue management ; cultures intermerdiaires / intermediate crops.

3. What are the conditions for adopting biosolutions in cropping systems?

The aim here is to find out what are the best conditions for the integration of biosolutions in cropping systems, by considering different points of view (scientists, farmers, people from the public or private sector, people working in crop protection, etc.). Several factors have been identified as having a significant influence on the adoption of biosolutions.

3.1 Coherence of cropping systems

One of the key points to emerge from the workshop was that the integration of biosolutions must be consistent with the existing cropping system. Biosolutions must be close to technical solutions that are already known, and therefore ready to be used, for a 'turnkey' appropriation. A new solution, in this case a biosolution, means that it has to fit into an existing technical environment. This solution must not just replace existing solutions, it must also be able to interact with all the solutions/levers already in place that address other issues. Indeed, for an efficient transition, particularly in crop protection (as in the case of biocontrol solutions), a more systemic approach is needed, involving a rethinking of cropping systems, with a rational choice of all the practices, depending on the context and so that they 'work' in synergy.

3.2 Regulations / Approval - Market

One of the points raised during this workshop was the importance of facilitating the market authorisation process and therefore of changing the regulations, especially for biocontrol solutions. Clarifying the status of biosolutions could therefore be a way of speeding up their adoption. Indeed, biosolutions call into question a whole area of regulation and require action to be taken on several sets of standards ranging from the Common Agricultural Policy to measures to protect agro-ecological infrastructures. Many areas of law, not just product-specific regulations, need to be reviewed to create a context that makes it easier to adopt and integrate biosolutions (Gimonprez, 2023).

To bring innovations to market more quickly, manufacturers will need to be trained in the regulatory framework and assessment processes will need to be adapted to the specific characteristics of these alternatives.

3.3 Effectiveness of biosolutions

The core concern of the farming world remains the effectiveness of solutions. Biosolutions must have proven their efficacy to be considered as viable alternatives to conventional solutions. The effectiveness of biosolutions, and therefore the assessment of their performance, must be different from that of conventional products. The analytical approach and the systems approach must be considered together when assessing the performance of biosolutions. Yield and/or quality criteria alone (protein levels, for example) are no longer satisfactory. Other criteria need to be considered, such as :
- Economic indicators (costs, farmer income, value creation, adaptation to markets, etc.) ;
- Agronomic indicators (soil fertility, sustainability, use of plant protection products, etc.) ;
- Environmental indicators (soil, water, biodiversity, etc.) ;
- Societal indicators (nurturing function, services rendered to society, etc.).

Levers, combined together, can bring the effect sought with a conventional product closer (Vanloqueren and Baret, 2009). There are many levers, and their combinations are even more numerous. Gathering data on these levers requires a large network of partners, particularly farmers. These collaborations will enable us to build robust technical references and create a new 'multi-criteria' evaluation method (Arvalis 2020-2021 activity report).

3.4 Supporting risk-taking

The main lever for supporting farmers who adopt biosolutions is public policy. Among the measures to be deployed, financial support for farmers who take risk is important. Different kind of support could be imagined such as a tax credit, investment aid, or aid coupled with a programme to diversify cover crops, for example (Grimonprez, 2022).

3.5 Taking account of the impact of climate change

Against a backdrop of agro-ecological transition and climate change, biosolutions could find their place in meeting the new challenges facing agriculture. The increase in the frequency of extreme events due to climate change could be the trigger for an in-depth rethink of cropping systems, incorporating levers to store carbon, for example. Carbon storage through the development of plant cover and landscape structures helps to mitigate climate change. In addition, biosolutions, and in particular biostimulants, could prove to be an asset in the face of climate change (Jacquet et al., 2022).

Agriculture needs to be multifunctional and face a number of challenges: fulfilling its role as a source of food in a context of agro-ecological transition, adapting to hazards and climate change, responding to increasingly segmented markets and exploring new sources of value. This means designing or redesigning cropping systems, prioritising actions according to the issues at stake and using a combination of levers. In addition, if biosolutions are to be deployed in agriculture, it is vital to develop continuing and initial training in biosolutions to ensure that the professionals called upon to advise on these biosolutions have the necessary skills.

4. What indicators or criteria are needed to ensure the widespread adoption of biosolutions?

The third question posed to workshop participants concerned the criteria/determinants to be taken into account to improve the adoption of biosolutions on a large scale. The term "large scale" was taken to mean that of territories, with the inclusion of all the stakeholders in these territories and their expectations in this reflection, and the taking into account of the challenges and constraints of a given territory. Two major levers of action were identified to encourage the adoption of biosolutions on a regional scale, biosolutions being considered as a product.

4.1 What technical criteria should be considered when adopting biosolutions?

The first lever concerns the technical aspects associated with these biosolutions. The adoption of biosolutions will depend on the development and marketing of solutions that are sufficiently 'generic' to be used in a variety of contexts, from the point of view of soil and climate or cropping systems, and in relation to different targets (in the case of biocontrol solutions). At present, too few uses are covered by biosolutions. The adoption of biosolutions also means that these solutions must be sufficiently characterised in terms of their modes of action, which are often complex and dependent on factors that modulate their effects, when they arrive on the market. These factors determine the effectiveness of these biosolutions, which is a key determinant of their adoption (whatever the scale). However, the notion of effectiveness needs to be reconsidered when dealing with this type of solution. Indeed, participants agreed on the need not to confine the evaluation of biosolutions to their impact on yield alone. Finally, participants stressed the need for solutions that are ergonomic to use (ease of application, frequency of application, etc.).

4.2 What socio-economic criteria should be considered when adopting biosolutions?

The second part concerns the socio-economic aspects of biosolutions. It emerges that the adoption of these solutions by the primary users, i.e. farmers, can only be achieved by remunerating the 'co-benefits' associated with the use of these products. The aim is to be able to put a financial value on the enhanced ecosystem services (soil fertility, biological control, etc.) provided by biosolutions and the resulting conservation of resources (water, soil, air). Taking these co-benefits into account and paying for them would make it possible to at least partially decouple biosolutions and yields, so that the added value of these solutions is not assessed solely in terms of maintaining or even increasing yields, as is (too) often expected. This would also make it possible to improve the profitability of these products for both farmers and marketers, and thus improve the long-term viability of these solutions. However, questions need to be asked about 'who' is responsible for ensuring that the co-benefits are remunerated, and what are the specifications for assessing these co-benefits (obligation of means or of results)? How and by whom can local stakeholders be brought together to help pay farmers? As far as the socio-economic aspects are concerned, it is also clear that the solutions 'available' or to come must be understood and socially acceptable. For example, technologies such as sterile males for biocontrol may be rejected by society. The very application of many biosolutions, particularly foliar sprays, may also be rejected by the general public. It is therefore important not to neglect communication and education initiatives to ensure that these innovative solutions are accepted.

In conclusion, it can be seen that taking into account the co-benefits associated with the implementation of biosolutions will require a range of indicators that can be adjusted according to the areas under consideration, the issues at stake, the cropping systems in place and their soil and climate constraints. It will also be necessary to have a method for assessing and monitoring the transition of systems incorporating biosolutions, following the example of the methods developed as part of the low-carbon label, and moving away from a plot-by-plot and crop-by-crop assessment. Finally, the transition to and use of these solutions will mean accepting that there is no such thing as a "universal" bio-solution.

5. General conclusion

Biosolutions, whose actions are aimed at amplifying the ecological processes that underpin ecosystem services, are still often perceived as the counterpart to synthetic inputs, and are therefore used or can be used as a simple replacement for these exogenous inputs. However, because of their complex modes of action, these biosolutions need to be integrated into cropping systems in a way that is reasoned with the other agronomic levers, i.e. as part of a system redesign approach. Crop management also needs to be rethought, both from a health point of view and in terms of fertilisation, to help integrate biosolutions that are only partially effective overall. For example, with biocontrol solutions, the aim is to move away from the logic of eradicating a pest that is generally expected with the use of a conventional plant protection product, and instead seek to maintain pest populations below harmful thresholds. To achieve this, it is necessary to have management tools that enable biosolutions to be applied to crops at the 'right time', as well as indicators (other than yield) that enable the overall performance of systems incorporating biosolutions to be assessed. Finally, other strategies to support biosolutions and reinforce certain ecological processes (particularly those involved in biological regulation) can also be envisaged. These strategies are based on the conservation and management of semi-natural habitats, the spatial organisation of crops and an increase in cultivated biodiversity. They necessarily involve a change of scale, moving from management on a plot-by-plot basis to management on a wider landscape scale.

However, the large-scale adoption of biosolutions cannot simply be envisaged without a more in-depth analysis at regional level. This approach will require the region to be seen as a project area, with flexible boundaries linked to one or more development projects, and in which all the stakeholders are involved.

This translation forces us to reflect on a common driver for change and implicitly brings out a notion of impact attached to the organisation of space for services rendered (idea of a "territory optimiser", Figure 3).

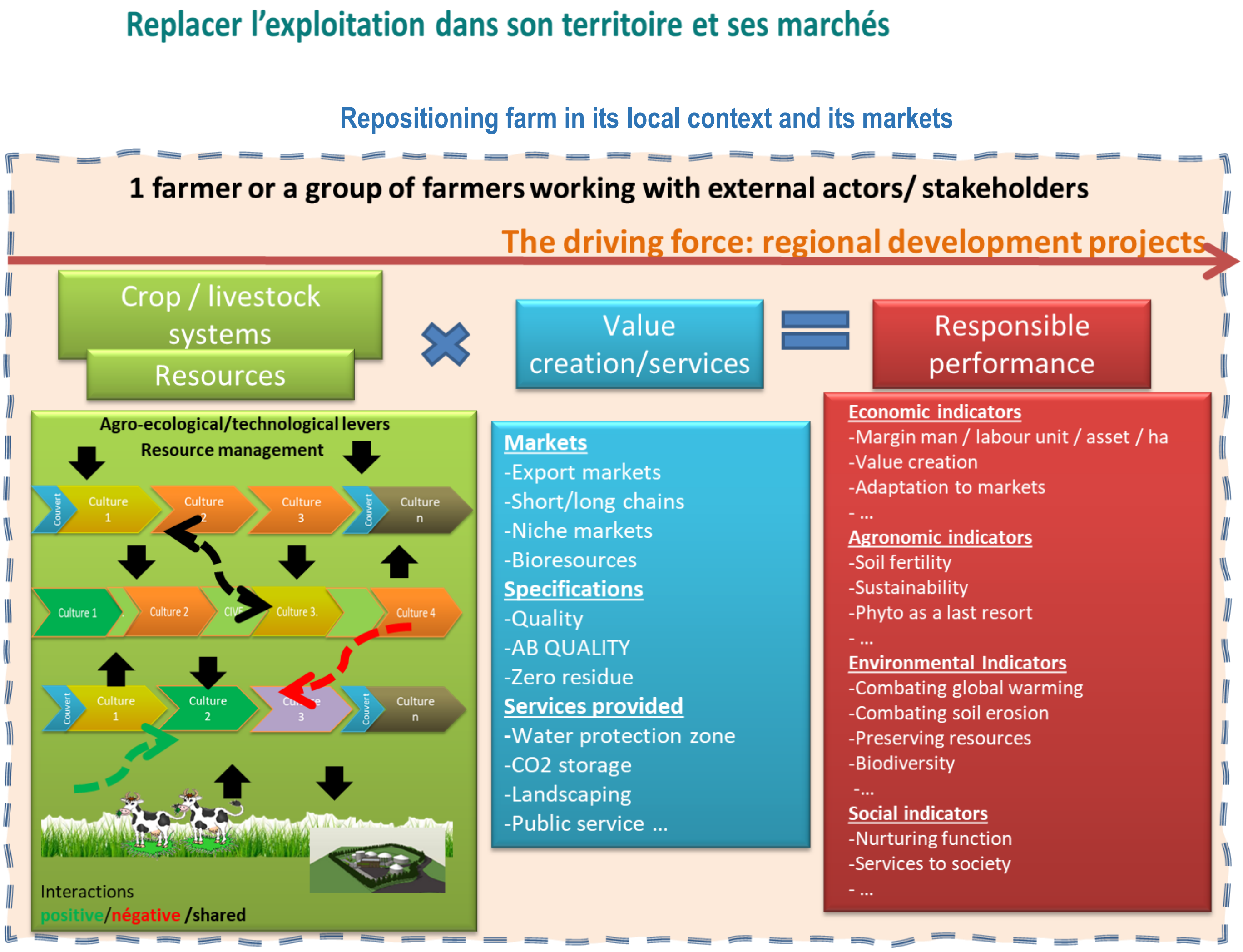

Figure 3: Representation of the concept of territory optimiser

Arable farming is present here in the form of a mosaic of cropping and potentially livestock farming systems, providing a wealth of farming systems. This diversity is a strength in terms of implementing agro-ecological production levers, gaining access to new operating resources (equipment, labour, but also the skills needed to manage these more complex systems in the future), creating interaction between systems, complying with new specifications and, above all, achieving new performance targets. Over and above the need for a driver for change and a shared portrait of multi-performance, this vision of the region raises the question of governance and the legitimacy of the players involved in transforming and managing a region. It also clearly raises the question of the link with future market specifications, a possible source of recognition and remuneration for ecosystem services rendered.

The paths that will enable biosolutions to be adopted in arable farming systems and these innovations to be disseminated on a large scale are therefore complex to organise. They require the removal of obstacles such as the technical limitations generally associated with these solutions (in particular the number of solutions available), the identification of the combinations of levers with which to combine these solutions to guarantee their effectiveness in different systems, the availability of the 'right' indicators (the concept of multi-performance) to enhance the value of these solutions, and the bringing together of all the players in an industry or a region, depending on the issues at stake, to achieve this. The transition to systems that make the most of biosolutions can therefore only be achieved on a long-term basis.

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 Artificial Intelligence Assisted Technologies in the Drafting Process.

The authors have used artificial intelligence-assisted technologies to translate from French to English.

Author ORCIDs

SLEZACK-DESCHAUMES Sophie: https://orcid.org/0000-0001-8019-1115,

Authors' contributions

TRIOLET Marion, SLEZACK-DESCHAUMES Sophie, PIERSON Pascaline : conception, writing of the article

TRIOLET Marion, SLEZACK-DESCHAUMES Sophie, CHARLIER Gaelle, JEANNETEAU Guillemette, PLAISANT Isaac, PIERSON Pascaline : running the workshop

Declaration of interest

None.

Acknowledgements

The authors would like to thank the Bio4Solutions Chair and its sponsors (BASF, LORCA, PAT, AGRAUXINE) for their support. The authors would also like to thank ENSAIA and its agronomy students for their participation and assistance.

References :

Arvalis, Institut du Végétal (2021) Rapport d'activité 2020/2021, Céréales Fourrages Lin fibre Maïs Pommes de terre Tabac. Paris. Available at: https://www.arvalis.fr/l-institut/nos-actualites/rapport-dactivites-arvalis-2020-2021 (Accessed on: 15 September 2023).

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.

Fortun-Lamothe L., Thénard V., 2015, L'agroécologie en élevage : des principes à l'action Journée Agroécologie et Elevage - 4 December 2015.

Grimonprez B., 2022. Alternatives to conventional pesticides: the path to standardisation. Droit de l'environnement [La revue jaune], 309, pp.84 (hal-03594916).

Grimonprez B., 2023. Agricultural pesticides: a variable for adjusting food requirements to available natural resources. (hal-03944413).

Jacquet F., Jeuffroy M. H., Jouan J., Le Cadre E., Malausa T., Reboud X., Huyghe C., 2022. Zero pesticides: a new research paradigm for sustainable agriculture. Editions Quae, 244 p.

Meynard J.M., 2008. Produire autrement : réinventer les systèmes de cultures. In: Reau R. et Doré T. (Eds.), Systèmes de culture innovants et durables, Editions Educagri. pp. 11-27.

Meynard J.M., 2012, Associer productions animales et végétales pour des territoires agricoles performants. CIAG polyculture élevage, Poitiers.

Therond O., Duru M., Roger-Estrade J., Richard G., 2017. A new analytical framework of farming system and agriculture diversities. A review. Agronomy for Sustainable Development 1-24.

Vanloqueren G., Baret P.V., 2009. How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations, Research Policy, 38: 971-983.

Wezel A., Bellon S., Doré T., Vallod D., David, C., 2009. Agroecology as a science, movement or practice. Agronomy for Sustainable Development 29: 503-515