Biosolutions: overcoming the substitution paradigm for environmentally friendly vegetable production in Guadeloupe

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Reducing the use of phytopharmaceutical products in vegetable production systems is one of the objectives of sustainable production. In both mainland France and the French West Indies, stakeholders are experimenting with various alternatives to pesticides, including biocontrol and biostimulants. However, the dissemination of these technologies remains limited and the substitution paradigm remains predominant, hindering the thorough redesign of cropping systems required for a successful ecological transition in agricultural production systems. We describe here a study performed in Guadeloupe, in which agricultural professionals were asked to identify obstacles and levers for the deployment of these biosolutions. We used different methodological sequences (diagnosis, exchange workshops, co-design workshops) and included a wide range of stakeholders (farmers, advisors, researchers, public stakeholders, agricultural suppliers) in this study, and we analysed the strategies of local stakeholders regarding the use of biosolutions. We found that real opportunities to move away from the substitution paradigm exist, but remain rare. We also found that the implementation of biosolutions requires a strengthening of local co-ordination between the various stakeholders in agrifood systems, to take agriculture along a true path of viable transformative change.

Keywords: co-design, biocontrol, biostimulants, territorial scenarios, coupled innovations

1. Introduction

In both mainland France and the French West Indies, the vegetable sector is confronted by a number of conflicting challenges, including protecting human health, producing high-quality vegetables, reducing the environmental impact of systems, and promoting the sustainability of farms. At the heart of these challenges is a strong desire to make agriculture “greener” (Duru et al. 2004), and one of the chief objectives for achieving this aim is reducing the use of plant protection products. The design of pesticide-free farming scenarios necessarily requires a systemic approach to the food system (Mora et al. 2023), but it also implies the adoption of a new paradigm. This new paradigm is based on the design, combination and appropriation of innovations at different scales, from the individual plant to the entire territory (Jacquet et al. 2022).

Biocontrol and biostimulants

Alternative strategies to the use of plant protection products include biocontrol and biostimulants. In France, biocontrol is defined by the Ministry of Agriculture as "all crop protection strategies that rely on the mobilisation of natural regulators", in other words, all strategies optimising the agro-ecological functions of crop systems and the ecosystem services they provide. Biocontrol is, thus, based on the principle of managing pest populations rather than eradicating them. Biocontrol products favour the use of natural mechanisms and interactions governing the relationships between species in their natural environment[1] . The diversification of biocontrol strategies and their economic models is one of the main levers identified for a shift in paradigm towards pesticide-free agriculture (Jacquet et al. 2022). The most

[1] Article L.253-6 of the Rural and Maritime Fishing Code

recent European regulations on biostimulants came into force on July 16th 2022[2] and define biostimulants as fertilisers with the function of stimulating plant nutrition processes independently of the nutrients they contain, with the sole aim of improving one or more of the following characteristics of plants or their rhizosphere: the efficiency of soil or rhizosphere nutrient use by the plant, nutrient availability, tolerance to abiotic stress, and the qualitative characteristics of the plants and/or their rhizosphere. Biocontrol and biostimulants are grouped together under the umbrella term “biosolutions”, which also encompasses biofertilisers and adjuvants. All these biosolutions are governed by national and European laws (see appendix) and form levers for promoting an agro-ecological transition towards better overall plant health, with plants better able to tolerate stresses both biotic (diseases, pests, etc.) and abiotic (water stress, thermal stress, etc.).

A substitution rationale is generally employed to introduction biosolutions into cropping systems (Hill & MacRae, 1995), with the biosolution replacing a synthetic plant protection product. The dominant substitution model is driven by the development and marketing of new inputs (crop protection agents, plant extracts, pheromones, etc.) by a company, followed by the large-scale distribution of these inputs to growers, often independently of the local conditions of use. Farmers then introduce these new biosolutions into their cropping systems as an input, much as they would for a conventional plant protection product. Approaches of this type are anchored in the substitution paradigm, which is characterised by a use of inputs in a business model derived from that of the agrochemical industry. However, the implementation of biosolutions can also lead to the redesign of cropping systems, to ensure the coherent use of these new inputs with other elements of the cropping system (*e.g.* rotations, fertilisation methods, weed control). It is also advisable to initiate a redesign process when biosolutions are produced on the farm. Redesign can make these alternative techniques more effective for pest control, but requires a much more detailed rethink of existing systems (Wezel et al. 2014).

Market gardening in Guadeloupe

The geographic situation of Guadeloupe (insularity, humid tropical climate, small size) exposes this island to strong biotic pressures (i.e. weeds, diseases, pests), environmental pressures (i.e. drought, cyclones) and anthropogenic pressures (i.e. difficulties accessing agricultural land, an ageing population, urbanisation). Its agricultural dynamics are marked by the co-existence of so-called "export" crops, such as sugar cane (processed into rum), bananas and melons, and crops destined principally for the local market, such as fruit and vegetable crops (tubers, vegetables). The two main crops in the market garden sector are melons and tomatoes, for which 6,000 t and 4,000 t, respectively, were produced in 2021 (Agreste, 2021). These crops are grown on small areas: 75% of farms in Guadeloupe are less than 5 ha in size (Agreste, 2021). The agroclimatic conditions in Guadeloupe, which are particularly favourable for the development of pests and diseases (emerging diseases, invasive species, etc.), are a major constraint on both melon production for export and vegetable production for the local market. In both cases, finding alternatives to the use of phytopharmaceutical products is a real challenge in the context of a goal of sustainable development and the maintenance of agriculture, at a time at which increasing numbers of crops grown in tropical environments no longer have approved solutions for pest and disease problems (orphan crops).

In terms of organisation, 27% of Guadeloupe's market garden producers (including those growing melon for export, a commodity essentially supported by a single group) belong to one of the sector's four professional organisations (Agreste, 2021). The other producers are mostly independent or belong to other groups, mostly associations. Thus, the production sector comprises three key groups of stakeholders: farmers, professional organisations and producers’ associations. The role of professional organisations is to plan and centralise production, organise the sale of products, provide technical assistance to farmers and redistribute aid. Some of these activities are also covered by producers’

[2] European regulation 2019/1009EC to come into force in 2022

associations (in particular the joint sale of products and technical assistance, which generally takes the form of co-operation in the field and the sharing of experience).

Against this backdrop, the use of biocontrol and biostimulants remains rare in Guadeloupe. Support for these biosolutions is both highly dispersed and poorly structured. As a result, they are used over small scales and are not widely disseminated. Stakeholders wishing to develop such solutions (i.e. research and technical institutes, certain professional organisations or associations, some farmers) are confronted with a number of obstacles. However, new opportunities are gradually emerging in Guadeloupe, leading to increasing demand from producers for the development of new alternatives. These opportunities include: i) field evaluations of biocontrol solutions and biostimulants, co-ordinated to various extents and performed by diverse local stakeholders (farmers, producers' organisations, research teams, technical institutes, crop protection product suppliers, etc.), ii) scientific and technical events relating to biocontrol and biostimulants organised by local stakeholders, including events organised within the Agricultural Innovation and Transfer Network, which raises the profile of the work and disseminates its results, and iii) the development of dynamic partnerships between researchers and the market-growing sectors in the area. Together, these local initiatives are helping to foster a shared interest in the need to promote biocontrol and biostimulants as alternatives to plant protection products.

Towards the codesign of local scenarios for reducing the use of plant protection products

In Guadeloupe, as in mainland France, reducing the use of plant protection products is a 'complex', multi-scale (spatial, temporal, organisational), multistakeholder (extending from the fields of production to technical support, marketing, etc.) and multidimensional (biophysical, technological, socio-cultural, economic, institutional and/or political) problem, involving multiple interactions. Such problems cannot be solved by purely technical solutions, implemented incrementally, generally within a substitution paradigm (Casagrande et al. 2023). Instead, we now need to explore combinations of organisational and institutional solutions involving multiple stakeholders in the agrifood system, making it possible to implement technical innovations on the farm (in this case biocontrol and biostimulants). Such scenarios are described as "territorial" and are based on new or strengthened co-ordination between stakeholders to encourage the deployment of these innovations. As a result, stakeholders need to be involved in the design of innovations (Casagrande et al. 2023).

We have therefore focused on stimulating and co-ordinating collective initiatives and actions to develop proposals for biocontrol and biostimulants that are adapted to the local context, to generate an impetus for a collective aim to move away from the paradigm of substitution and to contribute to the redesign of agrifood systems.

We will first present the key stages in the process of co-designing territorial scenarios, and the analytical grid proposed (section 2) for analysis and discussion of the results of various codesign workshops held in Guadeloupe and as part of the Biosolutions Agronomic Innovation Forum (section 3).

1. Materials and methods

For the co-construction of territorial scenarios for the development of biocontrol and biostimulants with stakeholders in Guadeloupe, we (i) identified and mobilised the stakeholders we needed to involve in the co-design of territorial scenarios, (ii) shared with these stakeholders the knowledge required to identify obstacles and levers to the development of biocontrol and biostimulants in Guadeloupe and (iii) mobilised this knowledge in a process of co-design with the stakeholders concerned, to encourage their co-ordination in efforts to explore and implement territorial scenarios. The various stages (identification of obstacles and levers to the development of biocontrol and biostimulants, exchange workshops, co-design workshop, summary) and actions are presented in Figure 1.

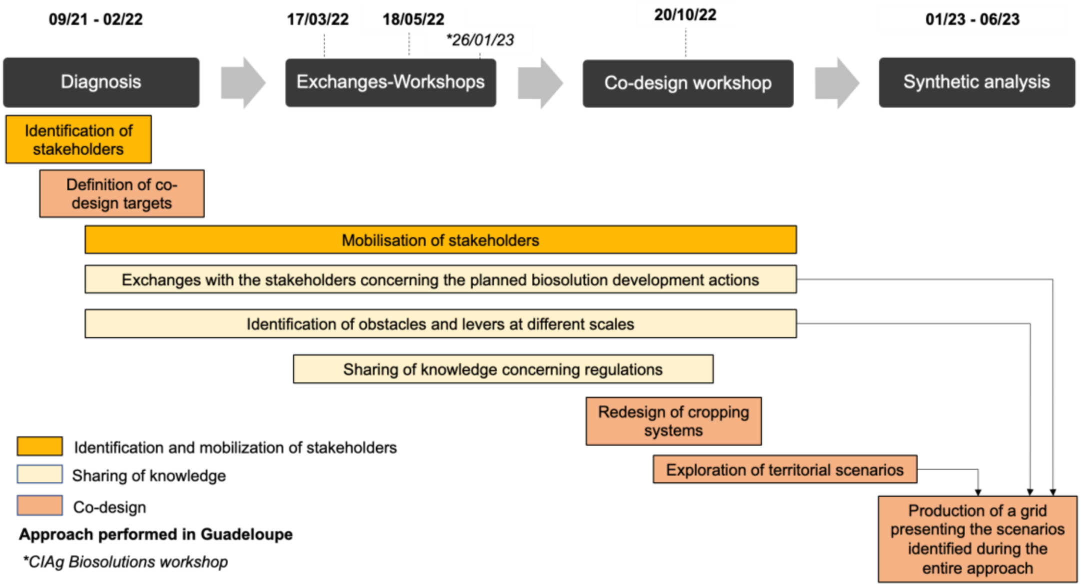

Figure 1: Stages and actions in the co-design process for territorial scenarios for the development of biocontrol and biostimulants in Guadeloupe

2.1. Identification of obstacles and levers to the development of biocontrol and biostimulants

We performed a diagnostic study based on the approach formalised by Casagrande et al (2023), to decipher and describe the functioning of the networks of stakeholders currently contributing to or limiting the development of these biosolutions. We performed a series of surveys with key stakeholders in the region, classified according to their areas of activity: production, support and technology, marketing, consumption and socio-political (Desombre, 2022). We surveyed 17 stakeholders between September 2021 and February 2022, as shown in Figure 2. The mobilisation of stakeholders was based on the identification of relevant structures and interlocutors bringing together a diversity of expertise, knowledge and viewpoints, to stimulate a dynamic of collective creativity.

Domain of activity	Function of territorial stakeholders	Number of stakeholders interviewed during the diagnostic phase
Production	Stakeholders involved in agricultural production	4
Support and technology	Stakeholders involved in the development and dissemination of knowledge	6
	Stakeholders involved in supplying inputs and agricultural equipment	5
	Stakeholders involved in the conservation, selection, evaluation and dissemination of genetic resources	0
Marketing	Stakeholders involved in the packaging, transport, transformation, marketing and distribution of products	1
Consumption	Stakeholders involved in communication and valorisation up to the consumption of the product	0
Socio-political	Stakeholders involved in the formulation and implementation of public policies and standards for agricultural production and foods (regulations, funding, certification)	1

Figure 2: Breakdown of stakeholders surveyed to identify obstacles and levers for the development of biocontrol and biostimulants (Casagrande et al. 2023)

2. 2 Knowledge-sharing workshops

Following the identification of obstacles and levers for the development of biocontrol and biostimulants, we adopted a co-design approach initially based on a presentation of the regulations governing biosolutions. This poster-based presentation, conceived as an intermediary object, was developed to meet two aims: to clarify the regulatory context and to share knowledge about the biocontrol and biostimulants used in Guadeloupe. We took advantage of two events organised by the *Réseau d'Innovation et de Transfert Agricole* in Guadeloupe to set up exchange workshops for the sharing of knowledge about regulations and agricultural practices involving solutions based on biocontrol and biostimulants. These two events — BikAgr'Innov (17/03/2022) and TransAgriDOM (from 16 to 20/05/2022) — brought together agricultural stakeholders from Guadeloupe (8 for BikAgr'Innov) and other French overseas areas (DROM, 37 for TransAgriDom). We aimed to assess stakeholders' knowledge about biosolutions, to draw up an inventory of existing practices in the region, as reported by stakeholders, and to make the regulations easier to understand and follow.

These 45-minute workshops each comprised three phases: (i) a phase in which participants were asked about the biocontrol and biostimulation solutions and practices they were aware of and/or had tested for themselves (exploration/ideation stage), (ii) a phase clarifying the regulations with the participants (knowledge contribution stage), (iii) a phase laying out the solutions and practices put forward by the participants on a shared summary poster to facilitate collective appropriation of the regulations.

The French and European regulatory frameworks are presented in the appendix and represented on figure 3, which shows the position of the different categories of biocontrol products (micro-organisms, chemical mediators, natural substances (including basic substances), macro-organisms) and biostimulants (biostimulant products incorporated into fertilisers and growing media, natural biostimulants (NBs)), and other fertilisers.

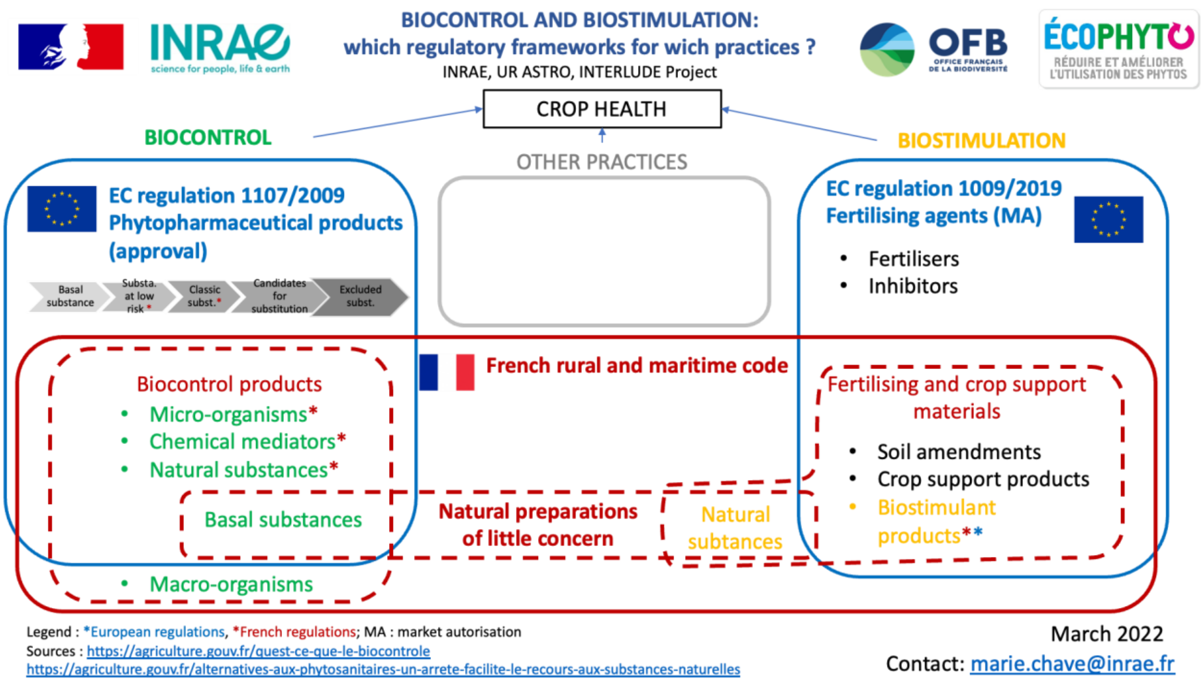

Figure 3: Poster presenting the regulatory frameworks applying to biocontrol and biostimulants (Eypert, 2022).

This poster also makes it possible to position all "other practices" not explicitly defined by the regulations but covered by the general definition of biocontrol strategies (see 1.1.) and likely to help decrease the use of plant protection products. These other agroecological practices include the use of service plants, crop associations and rotations, physical protection (e.g. insect-proof netting), the use of resistant varieties, optimised fertilisation, mulching, mechanical weeding, etc.

The data collected during these exchange workshops were used to prepare a co-design workshop exploring regional scenarios for the development of biocontrol and biostimulants.

2. 3. Co-design workshop

Following on from the knowledge-sharing stage, we organised and ran a workshop entitled "Co-designing territorial scenarios for the development of biocontrol and biostimulants in Guadeloupe" on October 20th 2022. The overall aim of this workshop was to explore and develop strategies for co-ordinating the development, by local stakeholders, of biocontrol and biostimulants for vegetable growers in Guadeloupe. It brought together 11 support and technology stakeholders (seven from the research and technical subgroup and four from the subgroup of input suppliers), and seven production stakeholders (mostly technical managers from professional organisations). The workshop was organised into three phases: (i) knowledge sharing and creativity training, (ii) redesign of vegetable cropping systems around an 'intermediate' design target, (iii) co-design of one or more regional scenarios for the development of biocontrol and biostimulants (the 'final' target).

The intermediate target of the cropping system redesign stage phase was the design of two vegetable cropping systems: a diversified market gardening system for local consumption and a melon production system for supermarkets and hypermarkets or for export. The next phase involved asking the stakeholders to project themselves into the territorial dynamics with the aim of constructing one or several strategies for the co-ordination of future concerted actions. The aim was to enable farmers to implement the cropping systems designed as intermediate targets and to achieve the objectives set by the group. We combined the cropping systems designed with associated concerted actions to explore territorial scenarios, combining technical innovations (biosolutions) with organisational and/or institutional innovations at farm or territorial level, involving changes in practices for various stakeholders of the agrifood system.

We used the "All in the same boat" tool to make this exploration interactive, fun and participatory. This tool is widely used to encourage the exploration of concerted collective action in brainstorming sessions. It can be used to represent trajectories towards a clearly stated goal (in this case, the two co-designed farming systems, symbolised by an island in the middle of an ocean), and to mobilise stakeholders, symbolised by the crew of a boat, to achieve this goal by working together. The participants have to imagine different actions, symbolised by downwinds in the form of arrows, to be performed collectively to overcome the obstacles, symbolised by rocky reefs placed along the route (figure 4).

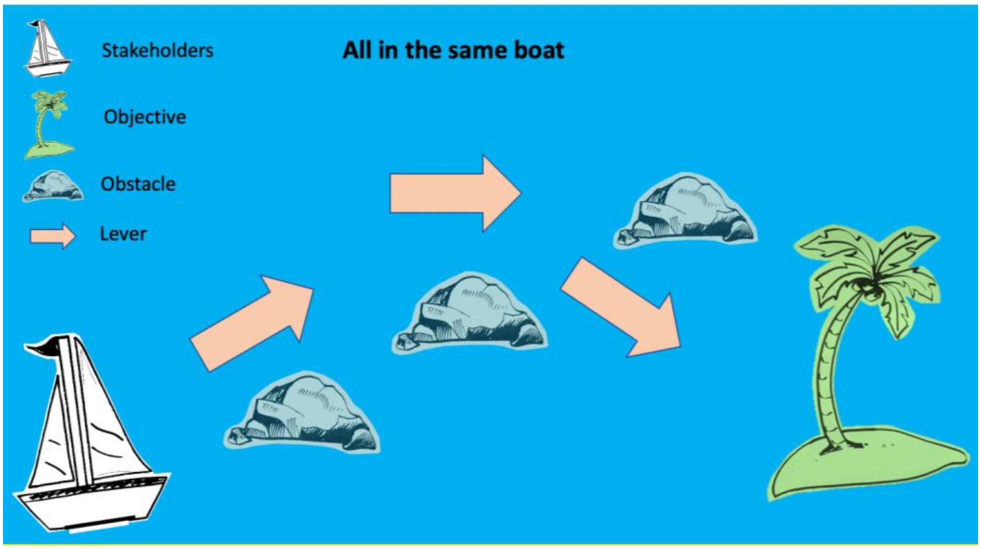

Figure 4: "All in the same boat" tool (adapted from https://www.worklab.fr/telechargements/bateau.pdf, drawings by Adriana Courteille)

The participants were asked to complete an action sheet to make the actions mentioned in the "All in the same boat" tool tangible. This action sheet could refer to stakeholders not present at the workshop, existing or non-existent, and to resources already existing or to be created (Boulestreau, 2021).

2.4. CIAg Biosolutions workshop

A workshop on "Territorial development of biosolutions for vegetable production systems in Guadeloupe" was held at the CIAg "Biosolutions: innovation processes and changes in technical systems in agriculture" meeting on January 26th 2023 in Nancy. The aim of this workshop was to take stock of the biocontrol products, biostimulants and agroecological practices proposed by the participants and to identify the obstacles to their implementation, comparing them with those identified in Guadeloupe. This workshop brought together 16 participants: 10 from the support and technology field (7 stakeholders involved in the development and dissemination of knowledge and three in the supply of agricultural inputs and equipment) and six students. This workshop was divided into two phases: i) Sharing knowledge about biosolutions, ii) Identifying obstacles to the regional development of these biosolutions. This workshop used the "Biocontrol and Biostimulant Regulatory Frameworks" poster (Figure 3) and an adaptation of the "All in the same boat" tool (Figure 4).

2.5. Drawing up an analysis grid for summarising the results

The biocontrol and biostimulation solutions envisaged and/or implemented by the various stakeholders reflect different strategies anchored in “greening” approaches of different intensities and requiring greater or lesser levels of crop system redesign (Duru et al. 2004). For example, some aim primarily to replace synthetic phytopharmaceutical inputs with biocontrol products and/or biological inputs such as auxiliary macro-organisms or products based on beneficial micro-organisms. Others aim to redesign cropping systems by adopting a systemic approach and promoting local biodiversity to increase the efficiency of biocontrol strategies. These strategies, implemented by stakeholders or groups of stakeholders at different levels, are levers for the agro-ecological transition.

Once the obstacles and levers for reducing the use of conventional plant protection products had been identified, an analysis grid, adapted from that of Sylvander et al (2006), was applied, using two axes to qualify the use of biosolutions. The first axis discriminates between different ways of integrating biosolutions into cropping systems (substitution vs. redesign) and the second axis measures the degree of collective involvement (individual, corporatist or sectoral/territorial governance) (Figure 5).

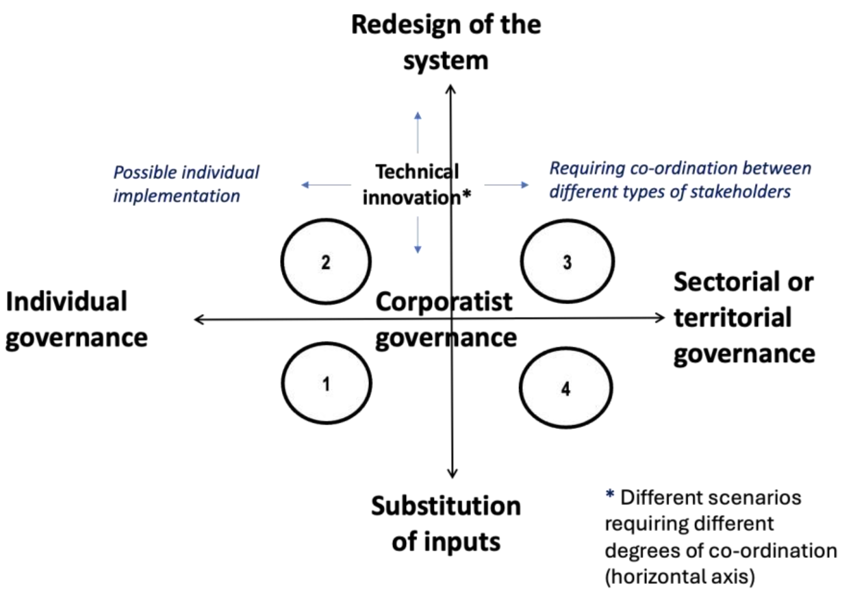

Figure 5: Grid for analysing and discussing scenarios designed for the development of biocontrol and biostimulants (grid adapted from Sylvander et al. 2006 by Eypert 2022 and Casagrande et al. 2023).

Before the co-design workshops, four types of potential scenarios imagined by the team of researchers were positioned on the grid, each in one of the four quadrants:

- Scenario 1: Substitution of inputs X Individual or corporatist governance,
- Scenario 2: Redesign of systems X Individual or corporatist governance,
- Scenario 3: Redesign of systems X Sectoral or regional governance
- Scenario 4: Substitution of inputs X Sectoral or territorial governance.

These theoretical scenarios were used as reference situations in relation to the scenarios proposed and subsequently explored collectively. In the summary phase, which was performed internally by the project team, the actions and scenarios proposed throughout the process, from diagnosis to the co-design workshops, were analysed.

2. Results

3.1 Obstacles to the development of biocontrol and biostimulants

A number of obstacles hindering the development of biocontrol and biostimulants were identified in Guadeloupe and at the workshop held during the CIAg meeting. A comparison of the obstacles identified in Guadeloupe and at the CIAg meeting revealed several levels of convergence. In both cases, there was agreement concerning the diversity and nature of the obstacles:

- **Scientific and technical**: lack of references and knowledge about alternative solutions (effectiveness, composition, application methods), lower efficacy than for conventional products, difficulties packaging and storing alternative products, changes in practices or even technical itineraries brought about by the integration and use of these products, dependence on the supply and import of commercial products, difficulties accessing local resources and suitable equipment,
- **Economic and financial**: the cost of alternative products can jeopardise farm profitability, the funding of local collective initiatives is often delayed, and there is a lack of funding for research and development projects to co-design and test these alternative technologies,
- **Cognitive and sociological**: the mentality of Guadeloupe's ageing farming population (reluctance to change, aversion to risk and investment), the lack of knowledge and training among farmers, but also the lack of time, difficulties sustaining collective initiatives and actions (relationships, contractualisation, trust) and in sharing resources (both material and intellectual),
- **Regulatory, legislative and administrative**: cumbersome administrative procedures for obtaining marketing authorisation and applications for aid/funding out of step with the agronomic scale, difficulties understanding regulatory constraints (authorised/prohibited products and substances).

For this last point, specifically in Guadeloupe, an analysis of the surveys performed to identify obstacles and levers for the development of biocontrol and biostimulants revealed that continual changes to regulations on biocontrol and biostimulants were a major obstacle. These regulations were poorly known by those working in the field, and their complex and restrictive nature limited their application by farmers, thereby also limiting the use of biocontrol and biostimulants. In addition, the lack of shared knowledge and references concerning the efficacy of traditional practices for enhancing plant biodiversity (e.*g.* association of service plants, production of purins from local resources) left farmers reluctant to implement these techniques. Finally, the lack of co-ordination between stakeholders involved in research and development, in particular, and the reluctance of certain stakeholders in the production sector to collaborate were also major obstacles to the use of biocontrol and biostimulants.

The obstacles to the use of biocontrol and biostimulants identified in Guadeloupe were relatively generic. However, the associated levers and their implementation in Guadeloupe are necessarily specific. They constitute a subset of the generic levers for biosolutions, the implementation of which in Guadeloupe depends on the specific context, stakeholders, soil, climate and cultural features of this island. An example is provided by the production of biostimulants, such as purins made from local plants on the farm, a practice that is developing on a farmer-to-farmer basis in Guadeloupe.

3.2. Appropriation of the regulations

Given the complexity of the regulations on biocontrol and biostimulants (Figure 3 and appendix), this methodological knowledge-sharing stage was intended to respond to a request for clarification from stakeholders, and to initiate the territorial scenario exploration phase by listing the biocontrol techniques and biostimulants known to stakeholders.

At both the Guadeloupe and CIAg workshops, all categories of biocontrol and biostimulant solutions were discussed, together with other agro-ecological practices, by the stakeholders, who provided about a hundred examples, demonstrating the diversity of knowledge and of the solutions already tested. The proposals generated by the Guadeloupe and CIAg workshops are illustrated in Figure 6.

Figure 6: Frequencies with which the various solutions (biocontrol, biostimulants, other practices) were cited by participants in the Guadeloupe and IACG workshops.

The "other practices" category was the most frequently cited category at both the Guadeloupe and CIAg workshops. Within this category, service plants (i.e. repellent, relay or mycorrhizotrophic plants) and associated crops (i.e. in market gardening beds or agroforestry) were the most frequently cited in Guadeloupe, whereas the use of resistant varieties, landscaping and physical barriers were the measures most frequently cited at the CIAg workshop. The importance accorded to "other practices", which, by their very nature, do not fit into the substitution paradigm, reveals the considerable opportunities for mobilising agroecological practices without limitation to marketed inputs identified by the stakeholders.

The next most cited categories in Guadeloupe were fertilising agents (21%) and natural substances (16%), contrary to the findings for the CIAg workshop. Natural biostimulants, micro-organisms and macro-organisms accounted for between 8 and 12% of the proposals at both the Guadeloupe and CIAg workshops.

Regardless of their category, most of the solutions proposed during the workshops are likely to be used at different levels, ranging from substitution to system redesign, depending on the willingness of stakeholders, particularly farmers, to change their practices and resources. These findings lay the foundations for territorial scenarios for the development of biocontrol and biostimulants, which may involve the development of 'industrial' products or solutions manufactured 'on the farm', and the implementation of more systemic practices forming part of broader strategies for the redesign of agricultural systems.

These first two knowledge-sharing stages highlight the wealth of knowledge and experience among the stakeholders of Guadeloupe's vegetable sector on which we can draw in the co-design of regional scenarios for the development of biocontrol and biostimulants.

3.3. Scenarios explored by stakeholders during the co-design workshop

As part of the workshop on co-designing territorial scenarios in Guadeloupe, two action sheets were produced following discussions between the two subgroups: a 'Sustainable melon-growing system' sheet and a 'Viable and sustainable cooperative market-gardening system

at farm level' sheet.

According to the participants in the 'Melon' workshop, the territorial scenarios explored for the design of 'sustainable melon cropping systems' should aim to 'implement biosolutions to improve the technical itinerary for this crop (balance between environment, economic profitability, product image)'. They should be supported by producers (implementation, ownership), research centres (experimentation) and technical institutes (experimentation, ownership) and should involve input suppliers (offering concrete solutions), consumers (medium- and long-term), institutions (the region, DAAF, ministries, policy support and setting up dossiers) and the *Société d'aménagement foncier et d'établissement rural* (SAFER - land management for farm establishment). The group proposed the co-construction of a multisite experiment for evaluating biosolutions in the field, this project being integrated into the Sustainable Melon Plan.

From the outset of the discussions, the "Diversified Market Garden Systems" group distinguished two distinct objectives for the exploration of territorial scenarios. The first was the "co-design of co-operative market-gardening cropping systems including biosolutions"; the second was the "co-design of individual market-gardening cropping systems including biosolutions". A consensus was reached on the common objective of improving exchanges concerning the research and experimentation dynamics relating to biosolutions in Guadeloupe. Research bodies, technical institutes and producers' organisations should undertake the necessary actions, with the involvement of institutional partners, biosolution suppliers and training bodies.

The involvement of stakeholders in the co-design workshop made it possible to initiate the co-construction of territorial scenarios. However, the scenarios put forward at the end of this workshop by the "Melon" and "Diversified market gardening systems" groups were not particularly well developed and were mostly based on the substitution paradigm. Most of the actions identified at the end of the diagnostic and exchange workshops were not mentioned during the group discussions of the more forward-looking co-design workshop. For example, one of the original features of the Guadeloupe context, the on-farm production of biostimulants, for use at different levels of organisation, was not mentioned in these scenarios. The structuring of a local and collective unit for the production of biocontrol solutions and biostimulants from endogenous resources mentioned by certain stakeholders during the diagnostic stage was not addressed either. There may be several reasons for this: the participants involved in the workshop having too little time to develop these themes, or the absence of stakeholders involved in such initiatives (such as the principal farmers involved, for example) from the workshop.

3.4. A summary of the scenarios identified at the various stages "from diagnosis to the co-design workshop"

In addition to the draft scenarios resulting from the co-design workshop (3.3), various proposals were developed by combining the results obtained throughout the process from the diagnostic step to the co-design workshop. These proposals are positioned on the analysis grid presented from section 2.5 in Figure 7.

The various types of theoretical scenario proposed in section 2.5 were, thus, refined and illustrated on the basis of local dynamics identified throughout the process. At each stage (diagnosis, exchange workshops, design workshop), the scenarios presented in Figure 7 were developed on the basis of discussions with stakeholders on the development of biocontrol and biostimulants, and on the scenarios co-constructed as part of the design workshop. The nature of the co-ordination required for the implementation of the scenarios was specified during the summary phase, which initially involve only the project team.

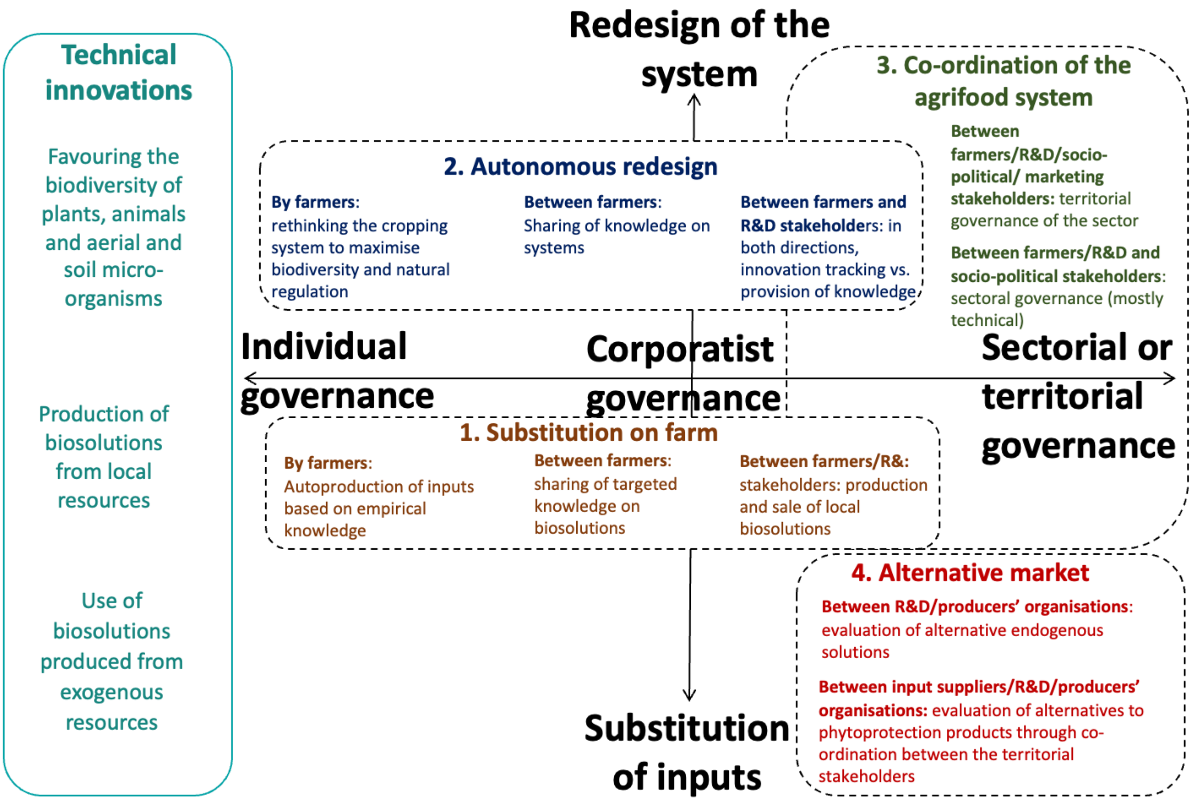

Figure 7: Representation of territorial scenarios for the development of biocontrol and biostimulants based on the diagnostic findings and the outcomes of the exchange workshops and the co-design workshop.

In scenario 1, "On-farm substitution", innovations come from the field and are based on ancestral knowledge and the farmers' empirical knowledge of how their system works. The governance of this scenario may operate: (1.1) at the level of individual farmers experimenting independently with the production of biostimulants from local resources, and seeking information about scientific results and regulatory constraints to construct their own biosolutions, (1.2) at the level of groups of farmers relying on peer-to-peer sharing and advice within producer associations and organising collective biostimulant demonstration and manufacturing workshops, for example, possibly setting up a collective or private platform for biosolution production or (1.3) through interactions between farmers and research and development organisations. In this scenario, technical and research centres and institutes can take an interest in the solutions developed by farmers ("innovation tracking") with a view to making them more generic, understanding the underlying mechanisms and determining the optimal methods and conditions for application and efficacy.

Scenario 2, 'Autonomous redesign', involves a large number of farmers making wide-ranging changes to their practices, with the redesign of the cropping system both spatially and temporally (crop associations and rotations). As in scenario 1, governance may operate at different levels: (2.1) the farmers may be completely autonomously, rethinking their cropping systems to mobilise plant, animal and microbial biodiversity. Some are inspired by traditional practices and knowledge inherited from the Creole Garden, leading them to reorganise/recreate associations and rotations; (2.2) the re-design process may be undertaken by peers, with farmers exchanging information with each other on a regular basis and organising the marketing of vegetables through the sale of baskets of mixed vegetables, for example; (2.3) farmers may interact directly with research and development organisations. The dissemination of knowledge and expansion to a wider area are based on these 'leading' farmers, who are often called upon to give demonstrations and testimonials.

Scenario 3 "Co-ordination of the agrifood system" calls for territorial governance based on the involvement and co-ordination of stakeholders from different fields (socio-political, support and technology, marketing, consumption) and also possible, for scenario 3.1, production stakeholders to support farmers in the redesign of their cropping systems to facilitate the transition. In particular, with respect to the testimonies of the stakeholders and current or potential territorial dynamics, the aim is to create a link between the production, support and technology fields and to forge links between stakeholders in the socio-political and other fields in particular. Socio-political players are often perceived as being disconnected from the reality on the ground, and sometimes even as failing to provide sufficient support.

In scenario 4: "Alternative market for plant protection products", co-ordination between stakeholders (farmers, research and development, input suppliers, government departments) should make it possible to extend the range of biosolutions marketed to increasing numbers of uses appropriate for tropical conditions, thereby creating a genuine local alternative market that should gradually become more competitive and attractive than the current market. For this to be achieved, socio-political stakeholders must play a key role in the approval of substances and marketing authorisation for products, with conditions and procedures facilitating and accelerating the accessibility and availability of substitute products meeting the immediate needs in the field.

In the various scenarios outlined, technicians from technical institutes and the Chamber of Agriculture appear to play a structuring role. Based on their experimental work, they can act as an effective relay for devising ways of testing and experimenting with techniques and products on a Guadeloupe-wide scale. Acting at the interface between production and research, they could also play a key role in creating a network of farmer-experimenters (requiring appropriate contracts and partnerships) and removing cognitive barriers (individualism, mistrust, intellectual property, risk aversion). Conversely, they could help to generalise and refine scientific and technical knowledge, and even produce new knowledge to fill in the gaps relating to orphan uses and shortages of knowledge and references.

3. Conclusion

The process of co-designing territorial scenarios for the development of biocontrol and biostimulants in Guadeloupe revealed that i) stakeholders in the Guadeloupe vegetable sector, both individually and collectively, possess the knowledge and experience required to territorial scenarios for the development of biosolutions, ii) the involvement of these stakeholders at different stages of the co-design process and in different ways makes it possible to harvest and exploit this knowledge, iii) comparisons of this knowledge, including innovations already deployed in the field, with theoretical scenarios make it possible to open up new avenues of exploration and to develop territorial scenarios for the development of biocontrol and biostimulants.

Thus, the whole process, from the diagnostic step to the co-design workshops, produced 'building blocks' that, once assembled by the researchers with elements from other sources (theoretical scenarios, bibliographic data, etc.), can be used to develop more precise and, in some cases, more radical proposals for scenarios for the development of biocontrol and biostimulants in Guadeloupe. The combinations of technical and organisational levers proposed in the various scenario outlines are highly context-dependent, and it is now possible to take the proposals further by drawing on the dynamics of the stakeholders and opportunities for exploiting local biodiversity and lay knowledge for an innovative redesign of cropping systems incorporating substitution scenarios, which contribute to the overall approach.

Given the wide range of local scenarios for the development of biocontrol and biostimulants, there is a need to create a dynamic for co-ordinating the different actions. Such actions could be implemented through multistakeholder systems and platforms such as joint technology units (UMT) or the setting up of joint research and development projects. Co-ordination of this type is currently being formalised within a number of specific projects (e.*g.* the creation of the ISATI UMT *Conception d'innovations pour des systèmes agricoles et alimentaires agroécologiques en milieu tropical insulaire* in 2022 by the *Institut Technique Tropical* (IT2), the *Institut Technique de l'Elevage* (ITEL) and INRAE).

Declaration on Generative Artificial Intelligence and Artificial Intelligence-Assisted Technologies in the Drafting Process

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Appendix: French and European regulatory frameworks for biocontrol and biostimulants

The use of biocontrol and biostimulants in France is regulated at two levels: Europe, through European regulations defining the main principles and through the approval of active agents for plant protection, and national level, with the completion and refining of definitions and the proposal of a different classification and the issuing of national marketing authorisations for marketable products. National public policies can lead to changes in the regulatory framework, as was the case for the Labbé Law in 2014 in France. However, agricultural stakeholders do not always fully understand these regulatory frameworks.

At European level, biocontrol is not yet defined as such. EC Regulation 1107/2009 applies to all plant protection products (i.e. all products used to protect plants). This regulation classifies the substances used for this purpose into four categories according to their level of risk. Substances can be used only if approved by the European Union and included in Appendix 1 of the regulations. A product containing an authorised substance can then obtain marketing authorisation at national level, allowing its sale, distribution and use for one or more purposes in the country concerned. In practice, the applicant must prove not only that the product is harmless to humans, animals and the environment, but also that it is effective and selectivee for the pathosystem (crop x pest combination) concerned.

In France, biocontrol is defined as "a set of plant protection methods **based on the use of natural mechanisms. Used alone or in conjunction with other plant protection methods, these techniques are based on the mechanisms and interactions governing relationships between species in the natural environment. The principle of biocontrol is therefore based on managing the balance of pest populations rather than eradicating them" (Ministry of Agriculture and Food Sovereignty).** Biocontrol products are defined in article L. 253-6 of the French Rural and Maritime Fishing Code as "agents and products using natural mechanisms as part of integrated pest management. They include, in particular, macro-organisms and plant protection products composed of micro-organisms, chemical mediators such as pheromones and kairomones, and natural substances of plant, animal or mineral origin". Plant protection products fall within the scope of EC Regulation 1107/2009, whereas macro-organisms for biocontrol are regulated exclusively at national level. In both cases, the General Directorate for Food issues marketing authorisations after assessment by the French National Agency for Food, Environmental and Occupational Health and Safety (ANSES). As far as macro-organisms are concerned, only non-indigenous macro-organisms used for plant protection purposes are covered. A decree issued on February 26th 2015 sets out the list (known as the "T0 list") of biocontrol macro-organisms authorised in France. This list is regularly updated by the General Directorate for Food.

Biostimulants were defined in a European regulation (2019/1009EC) that came into force in 2022, as fertilising products designed to stimulate the natural processes of plant nutrition. Biostimulants should not only provide nutrients, but must also help to improve one or more of the characteristics of the plants or the rhizosphere, such as the efficiency with which plants use the nutrients present in the soil or rhizosphere, the availability of these nutrients, the plant's tolerance to abiotic stresses, or improvements in the qualitative characteristics of plants and/or their rhizosphere.

In France, biostimulants are included in the regulatory framework for Fertilising Materials and Crop Supports (MFSC), governed by Article L. 255-1 of the Rural and Maritime Fishing Code. Fertilising materials are defined as "products intended to ensure or improve plant nutrition or the physical, chemical and biological properties of soils". This definition is broader than the European definition of biostimulation.

Unlike biocontrol products, biostimulants can be marketed at either European or national level, according to the manufacturer's wishes. Thus, biostimulant products marketed at European level and bearing the CE mark may be sold on the French market alongside biostimulant products marketed solely in France and bearing the FR mark. The marketing authorisation is issued by the General Directorate for Food after assessment by the National Agency for the Safety to Health of Food, the Environment and Work.

In addition, two specific cases in France fall within the scope of biocontrol and biostimulation. These cases are grouped together as natural preparations of low concern. Such preparations must meet two criteria:

they must be composed solely of *substances* of natural origin (thus excluding *agents* of natural origin, such as micro-organisms) and they must be produced by a simple, inexpensive process accessible to all (drying, maceration, etc.). The natural substances used may be:

- Destined for use as biostimulants and marketed freely in France if the substances of which they are composed are listed in the Public Health Code (Article D4211-11 listing the medicinal plants or parts of plants authorised for sale by persons other than pharmacists).
- Destined for use in plant protection, despite this not being their primary purpose: these substances (e.g., salt, sugar, vinegar) are basically marketed for other purposes but are useful for plant protection. These natural substances are then qualified as "basal substances" under French law, provided that they are listed at European level in Article 23 of Regulation 1107/2009/EC on the marketing of plant protection products.