Matière à débattre & décider

Livestock grazing systems and sustainable development in the Mediterranean and Tropical areas

Recent knowledge on their strenghts and weaknesses

Alexandre Ickowicz and Charles-Henri Moulin, editors

éditions Quæ

4. Inventions and innovations to promote the contribution of livestock grazing systems to the agroecological transition of agriculture

Mélanie Blanchard, M'hand Fares, Éric Vall

Introduction

Mediterranean and Tropical livestock grazing systems have significant assets to effectively contribute to the agroecological transition of agriculture (FAO, 2018b). These include contributing to:

- strengthening livestock farmers livelihoods and adding value in value chains;
- conservation and use of biodiversity services of the ecosystems in which livestock production takes place;
- and recycling of livestock co-products to improve the efficiency of agricultural activities.

In 2018, the FAO developed an original, synthetic and comprehensive framework of the major values that, at least theoretically, characterise agroecological food and farming systems (Wezel *et al.*, 2020). This approach is based on ten or so interdependent elements grouped into 3 main areas.

- The first cluster concerns the intrinsic properties of these systems: 1) diversity; 2) synergies; 3) efficiency; 4) resilience; 5) recycling.
- The second cluster involves the human and social values that support the agroecological transition: 6) co-creation and knowledge sharing; 7) stakeholder inclusion; 8) food culture and traditions.
- The third pole relates to the values facilitating the creation of an enabling environment for the agroecological transition: 9) the circular and solidarity economy and 10) responsible governance.

These elements illustrate how the agroecological transition of agricultural systems refers to multiple processes of change involving several levels of scale in order to adapt, invent and innovate in the ways in which livestock farming is conducted.

For many years, research has been aimed at studying and supporting stakeholders in the Mediterranean and Tropical livestock grazing sector in the processes of change in their activities, and more specifically in a perspective of agroecological transition of agriculture. The objective of this chapter is to present the main results illustrating this approach.

In the first part, we will briefly review some key definitions and concepts related to the notions of inventions and innovations and how we understand them in our work on changes in grazing systems.

In the second part, we present a first group of five case studies of what we have termed "inventions". These inventions contribute to the agroecological transition in livestock production in several ways: by reducing the use of synthetic inputs in breeding, by improving the efficiency of animal performance monitoring, by developing rapid access to operational knowledge in livestock production on the diversity of forage values and on the integrated weed management and finally by taking into account the social behaviour of animals within herds. This work focuses on the creation of:

• promising inventions such as:
  – a digital device for studying the social behaviour of livestock sheep and its possible applications to grazing management and animal health;
  – applications of near-infrared spectrophotometry for rapid and low-cost determination of the value of fodder and animal excreta;
  – prototypes emerging for adoption:
  – an electronic ewe overlap detector to eliminate the need for hormonal heat synchronisation in artificial insemination;
  – an automated walk-out weighing platform for sheep during grazing, to improve the accuracy of monitoring the nutritional status of the animals by reducing the number of weighing sessions;
  – a collaborative web portal for sharing and distributing information on weed management in grassland ecosystems on grazing and agro-pastoral farms.

The third part presents the results of work on supporting innovations at the production system and farm levels, aimed at improving the recycling of animal waste and developing alternatives to concentrated feed and supplementing annual fodder:

• the introduction of shrub fodder reserves on dairy farms to improve the diet of females in dry season production in Burkina Faso;
• support for the production of organic manure in trenches at the edge of cultivated fields to improve the recycling of animal waste and crop residue at lower cost.

Finally, the fourth part of the chapter will focus on organisational innovations, relating to the implementation of local and sustainable governance of livestock territories to better manage agro-sylvo-pastoral resources. The first two examples deal with organisational innovations to improve stakeholder cooperation in livestock product value chains:

• contracting to improve collective grazing practices in cultivated fields on a territorial scale;

• innovation platforms for more environmentally friendly and inclusive local milk production and collection in sub-Saharan Africa.

Other cases deal with organisational innovation for concerted and sustainable management of territories incorporating livestock activities:
• the development of a local land charter to manage access to and use of agro-sylvo-pastoral resources on a communal territory in Burkina Faso;
• the contribution of rotational grazing to forest restoration in the Brazilian Amazon.

When we refer to inventions and innovations in our research on livestock grazing systems, what do we mean?

Éric Vall, Mélanie Blanchard, M'Hand Fares

Inventions, innovations and change processes

The term "innovation" has become a key element in the process of technical, organisational and social change, and is often synonymous with the word "progress", which it tends to replace, but it deserves to be clarified and placed in its rightful place in this process of change (Guellec, 2009). According to Schumpeter (1911, 1939), this change process comprises three stages. The first phase is invention, which consists in the production of new forms of information (ideas, theories, models, etc.). The second phase is innovation, defined as a new device (product, process, service or organisational mode) effectively sold or implemented, sometimes adapted and finally adopted by a community of stakeholders. The third phase is distribution, which consists in the adoption of this new device (innovation) by a large part of the population. Currently, innovation is perceived more as a process than as an object or a product.

In this process, research, whether fundamental (aiming to produce information) or applied (with a more operational objective), appears to be the primary source of innovation[13]. But it is not the only one, because the production of fundamental or applied knowledge can also come from learning by doing, imitation or the purchase of technologies by stakeholders in the field.

Moreover, the relationships between these three phases are not unequivocal. Admittedly, a new concept (invention) can give rise to new products or processes that can be marketed (innovations) and that will spread widely if they meet a demand. But a new process (innovation) can in turn give rise to a new idea (invention), just as the diffusion can encourage the development of new products and ideas.

13. Targeted research ranges from research sensitive to societal issues (policy relevant) to research directly aimed at solving practical problems, taking into account the main localised interactions that necessarily affect its definition and the implementation of solutions (policy oriented). In both cases, the objective is to generate information that can be used for action on reality and to obtain a practical, context-specific result (Sebillotte, 2004; Guillou, 2004).

In the change process described by Schumpeter, innovation plays a central pivotal role between invention and distribution. These three interacting components form a systemic continuum. To characterise these innovations, we can contrast radical innovations (which involve a major change, e.g. the mobile phone) with incremental innovations (which are adjustments to the product or process at the margin, e.g. the latest version of a mobile phone). We can also distinguish between product innovations and process or organisational innovations. So, innovations are not only technological, but they can also be organisational. Most often, they are a hybrid of both types, both technological and organisational, and often appear 'in clusters (Schumpeter, 1939).

In all invention and innovation, there are technical components (objects) and organisational components (subjects), but it is obvious that depending on the invention or innovation, the technical component may be more important than the organisational component (as in the case of the use of a new type of fodder in livestock farming) and vice versa (for example, in the case of the implementation of new rules for managing the grazing resources of a territory).

To simplify matters somewhat, research converts money into knowledge, and innovation converts knowledge into money" (Anandajayasekeram, 2011). In reality, this process is a complex pathway full of feedback and interactive relationships involving science, technology, learning, production, policy and demand. This reality of the innovation pathway means that the responsibility of agricultural research organisations in this area does not end with the production of new technologies or know-how, as the success of an invention and innovation can only be claimed when the inventions are distributed, adopted and used (Anandajayasekeram, 2011), i.e. when the innovation has gone through the whole innovation pathway described by Schumpeter.

Generally, an invention becomes a successful innovation when:
- it contributes something new for the user,
- it is considered to be better than the existing,
- it is economically viable and socially acceptable,
- it is distributed.

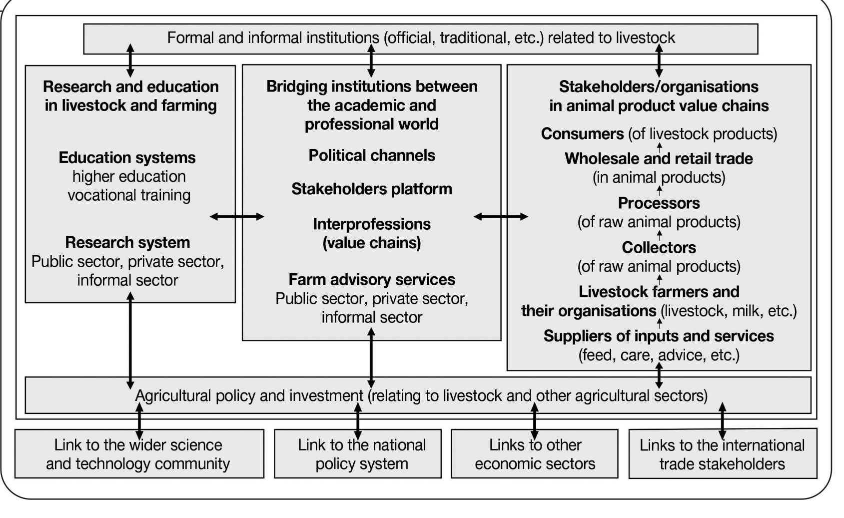
Space and environment of inventions and innovations

The process of change takes place in a space and an environment, described by its designers as an "innovation system" (Spielman, 2006.). In this approach, invention and innovation are defined as processes of production, access and implementation of new knowledge. The analysis focuses on strategic interactions that are complementary (positive, such as the emergence of innovation clusters) or substitutable (negative, such as lock-in phenomena in the face of change) and on the knowledge flows between the different stakeholders in the change process. In the innovation system, emphasis is also placed on the importance of the role of institutions in regulating the processes of invention and innovation, in particular in the area of learning (through practices, education and training, etc.), which is essential for the dissemination of innovations (Anandajayasekeram, 2011).

In its simplest form, the innovation system was initially represented as three main interacting components (Anandajayasekeram, 2011):
• the organisations involved in the production, distribution, adaptation and use of new knowledge;
• the interactive learning processes that occur when organisations engage in these processes and how this leads to new products and processes (innovation);
• and the institutions - rules, standards and conventions, formal and informal - that govern how these interactions and processes take place.

The outline of the innovation system relevant to our field of livestock systems research has been depicted in Figure 4.1. It includes:
• the modern and traditional sources of invention and innovation (agricultural research and education institutions, local know-how of livestock farmers and stakeholders);
• stakeholders in livestock value chains (from producers to consumers, private stakeholders, lobbies, NGOs);
• official and unofficial institutions involved in the formulation and implementation of agricultural policies and regulations;
• and at the intersection, organisations involved in linking and sharing knowledge and know-how between practitioners, policy-makers, teachers and researchers.

Figure 4.1. Theoretical diagram of a country-level agricultural innovation system (adapted from the World Bank, 2006).



The case studies presented in this chapter are obviously part of such an innovation system, with positioning and levels of interaction with system stakeholders varying according to their degree of development and the intrinsic characteristics of the invention and innovation.

After a brief review of the terms of innovation and their conceptual framework, we now present practical examples of inventions and innovations specific to Mediterranean and Tropical livestock grazing systems that enhance their contribution to the agroecological transition of agriculture.

Inventions for better sharing information and integrating natural processes into the management of livestock grazing systems

Jean-Baptiste Ménassol, Denis Bastianelli, Nathalie Debus, Eliel González-García, Samantha Bazan, Thomas Le Bourgeois, Vincent Blanfort

The agroecological transition of livestock systems, by turning its back on the simplification and artificialisation of practices and by relying on natural processes that are more complex to manage, requires the integration of a more extensive range of information than in conventional management methods. Consequently, the agroecological transition of livestock systems requires the development of devices (equipment, platforms, etc.) that allow practitioners to be better informed to support decision-making. This section presents work on devices invented in laboratories and research stations, not all of which were a priori intended to become an innovation. This work focuses mainly on the first stages of the path from invention to innovation, from the design of prototypes and the definition of their use by end users to a finished product, sometimes accompanied by a patent application.

Promising invention ideas

A digital device dedicated to characterising the social behaviour of sheep to facilitate flock management

Understanding the behaviour of farm animals is an essential lever for the implementation of sustainable farming practices, notably in livestock grazing where the animals enjoy considerable freedom of movement. It provides an opportunity to shift the emphasis away from the production objective by taking into account this essential dimension of animal welfare when adapting husbandry practices. Most farm animals have a high level of sociability: the group is the unit of expression of individual behaviour, such as the choice of sexual partner, cooperating to access resources or learning.

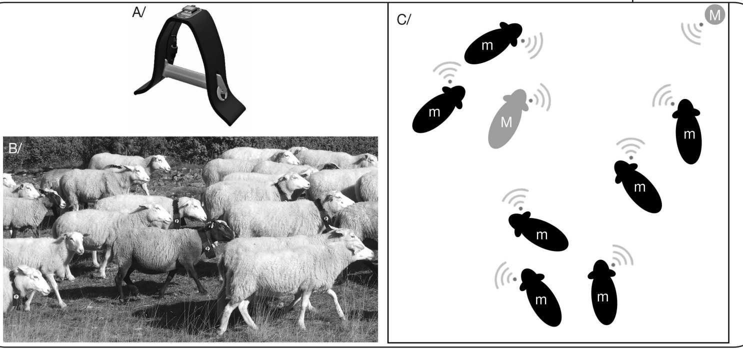
The analysis of social networks suggests, by means of the construction of complex social structures from interrelations between individuals, to analyse how individual behaviour structure the group and, in return, how the group influences individual behaviour. These analyses, which are mainly carried out on wild species, are of particular interest for domestic species, as they enable a third party, the manager (farmer, shepherd, etc.), to be associated with these two units (the individual and the group). Social network analysis can therefore be a tool for precision breeding, making it possible to coordinate the individual and collective scales. From the point of view of the transition to agroecological farming systems, this methodology contributes significantly to the elements of the first pole by improving the efficiency and resilience of systems:

- efficiency by maximising information intake and the impact of interventions by the manager. For example, by being able to infer the overall status of the herd from behaviours observed in a number of individuals and vice versa, or by interpreting herd structures to identify current or future disorders in targeted individuals;
- resilience by promoting an approach and social organisations adapted to the overall environment of the herd, in its biotic (including the manager(s)) and abiotic components. For example, this may involve grazing organisations that allow for integrated management of parasitism, adaptation in the face of diminishing resources or increasing predation pressure.

In order to develop this type of tool, it is essential to acquire information that allows the complex social structures that make up a herd to be constructed in a digital manner. In our case, the process of reflection and development towards invention was motivated by the absence of satisfactory existing solutions for our monitoring conditions. Initiated in 2016, these iterative developments between laboratory and field phases have led to a functional solution in 2019. The digital tool developed is based on a radio frequency (RF) sensor that measures inter-individual proximity (Figure 4.2).

The development of this tool was iterative. The in silico development phases were extended by intermediate field deployment phases, without animals, and then by farm roll-outs with increasing follow-up times. The intermediate roll-out aimed to test the performance of the hardware (battery, antennas, boxes, etc.) and software (control program for the mobile nodes and the master node) parts of the embedded system under simplified conditions. Deployment in livestock farming, in more complex environments, provided a more in-depth level of testing, notably on the durability of the means of embedding the sensors in the animals. These combined deployment phases regularly contributed to updating the hardware and software of the tool in order to approach the targeted monitoring objectives. They have also enabled other stakeholders to be involved in the development process, including engineers and livestock technicians, as well as farmers and shepherds. Their input was significant in anticipating certain herd behaviour to avoid system failure or in validating the means of incorporation and the configuration of the system to be adopted according to the type of terrain. The final architecture of the tool provides great adaptability in terms of field constraints for data acquisition, transmission and storage, but also in terms of energy autonomy and the general robustness of the installed device.

Figure 4.2. Digital tool for determining the social network of a herd by measuring inter-individual proximities.



A. 3D rendering of the collar. Inspired by a traditional bell collar, the bell is replaced by a PVC battery case that exerts a counterweight to keep the sensor in its waterproof case in the up position (here open). B. Photograph of a flock (Romane ewes from the La Fage experimental estate, Aveyron). Some individuals are equipped with the RF sensor mounted on the collar. C. Diagram of the on-board solution. The ewes are equipped with an RF sensor or mobile node (m), while a centralisation node or master node (M) can be mounted on an individual or fixed at the edge of the plot. The latter keeps pace with the mobile nodes and stores the acquisitions. Proximities between individuals are deduced from the quality of RF communication established between pairs of sensors (inversely proportional to distance). The constructed maps of the group's social network are analysed according to individual attributes and environmental events. Source: A) Théo Kriszt; B) and C) Jean-Baptiste Ménassol.

As for practical applications of understanding the social structure of a herd, we were able to set up a behavioural method for identifying the most representative individuals in the herd movement. This method, developed within the framework of the Clochète project[14], makes it possible to reason over the choice of individuals to be equipped with geolocation and activity sensors in order to maximise the efficiency of operations to monitor the mobility and use of surfaces by grazing herds. From a prospective point of view, this method will also be used to study the adaptation of herds in the face of predation pressure or a reduction in food resources. In the latter cases, the expected results are the definition of early behavioural indicators of alterations in the social behaviour of individuals (which may have an impact on their well-being), justifying targeted interventions by the farmer.

Near Infrared Spectrophotometry (NIRS) to facilitate the determination of forage value and the management of animal manure

In the field of animal feed, agroecological practices are leading to a diversification of feed resources, with the use of cover crops for two purposes, and less standardised methods of exploitation of fodder from multispecific grasslands (Baumont *et al.*, 2008).

14. http://idele.fr/clochete/ and http://vimeo.com/561497620.

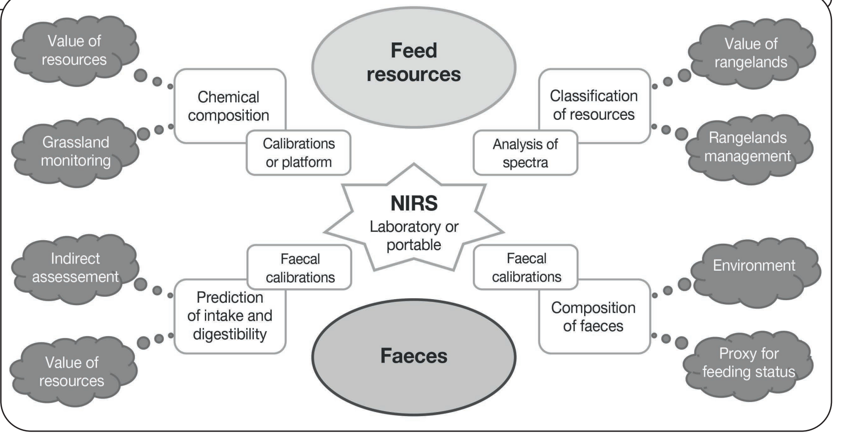
For farm management purposes or research on feeding systems, it is essential to characterise heterogeneous forage resources more frequently, more accurately and more reactively. The use of results for decision-making cannot be reconciled with delays in analysis of several weeks.

Near infrared spectrometry (NIRS) is a classic tool for rapid and inexpensive analysis of feeds and forages. The wavelengths in the NIR interact with the bonds between the atoms of organic molecules. The absorption of light is therefore related to the amount of chemical bonds and their interactions. The chemical composition of samples is then estimated by simply measuring the absorption of infrared light. Although routinely available in the animal feed industry, it is not yet widely used in livestock farming, and even less so in extensive livestock farming and in countries in the south. However, initially designed for the measurement of a few specific analytical parameters of feeds, its uses can now be extended to the analysis of the value of forages and animal dung, providing very useful information for the implementation and management of agroecological livestock systems (Bastianelli *et al.*, 2018).

Recently, following requests from research or by stakeholders in the field new approaches based on NIRS have been implemented (Figure 4.3).

Characterisation of complex environments on Mediterranean rangelands. Describing a rangeland by means of a list of the plants present and their nutritional value is of no use in grazing management. What use is a simple table of the chemical composition of a hundred or so possible “morsels” to a farmer or manager of a grazing area? NIRS can be used to propose a classification of food resources into functional classes. By simply

Figure 4.3. Near Infrared Spectrophotometry (NIRS) to facilitate the determination of forage and animal manure value.



taking a spectrum of edible plants, it is possible to assign them to a limited number of "functional classes" and consequently to reason out animal feed according to their suitability (protein feed, ballast feed, etc.), independently of the plant species present. The approach, already used in research (Azambuja *et al.*, 2020) can be applied by livestock farmers or managers of natural areas to assess the value of rangelands, carrying capacities, or even the need for supplementation for resource categories considered deficient in certain natural environments.

Indirect estimation of animal feed during grazing based on faeces analysis. Faeces provide access to various information, from a simple measurement of dietary indexes (nitrogen, lignin) to predictions of digestibility or ingestion, useful for steering livestock feeding systems, but also increasingly for environmental studies on modelling biogeochemical flows in grazing lands (nitrogen, organic matter and prediction of GHG) (Assouma *et al.*, 2018).

The provision of a "DoPredict" feed value prediction platform. It can be used to predict the composition and nutritional value of a sample from spectral data without the need for a specific calibration. The system compares the spectrum to a baseline and selects the closest individuals to establish a "local" calibration. This permits the prediction of the composition of less frequent plants or mixtures for which no specific calibration would be available. This platform centralises the prediction operation, taking advantage of unique reference bases and algorithms, so that the spectra can be decentralised and brought as close to the field as possible, without having to transport the samples themselves. Combined with measurements by portable spectrometers (Salgado *et al.*, 2013), this strategy provides a pooling of tools and a reactivity that allows farmers to benefit from the fastest and most accurate response possible for the characterisation of their resources.

The limits of the use of NIRS in farming include the cost of the equipment and the possibility of live field measurements, which is increasingly realistic with portable spectrophotometers (Salgado *et al.*, 2013). While the short-term prospects relate more to the use by livestock technicians or supervisory structures (as is the case on the island of Reunion and Madagascar), direct use by farmers is conceivable with the availability of less expensive equipment and their simultaneous mobilisation to, for example, improve the use of fodder resources and faecal management on farms.

Prototypes in the process of implementation

The electronic estrus detector in sheep

The seasonality of sheep reproduction is a key constraint in farming. Even in the case of breeds with little seasonality, such as most Mediterranean breeds, spring - corresponding to the natural sexual resting season - marks a slowdown in the animal reproductive activities. Hormone treatment programmes have therefore been developed to enable out-of-season reproduction. In agreement with the dairies, ewe dairy farms are getting organised, some of them using these hormone programmes so that the whole dairy basin can produce milk all year round, especially during periods of high demand. An undeniable advantage to these treatments is that they combine a high rate of induction of the ewe reproductive cycle with a high degree of inter-individual synchronisation. They can therefore be combined with inseminations, carried out on a whole flock at a fixed time. This practice gives access to the progress made possible by genetics, simplifies the work of farmers and limits health risks by eliminating the need to exchange rams between farms. However, the use of hormonal treatments is now being questioned and is already prohibited in organic farms, whose market share is growing. Practices must therefore evolve in order to better respond to the principles of agro-ecology and to the emergence of new ethical issues related to animal welfare and public health.

In this context, the electronic estrus detector Ovimate has been developed as an alternative to hormones in sheep farming, while still allowing farmers to use artificial insemination. Its working principle is based on the natural reproductive behaviour of sheep (Figure 4.4 A). The male is fitted with a leather harness, which includes an RFID (Radio Frequency Identification) reader. Each ewe mount triggers the reading of an RFID tag placed on the tail of the female. The date and time of the mount are then compiled with the identifiers of the two partners (Alhamada *et al.*, 2016). A video presentation is available on the European SheepNet website[15]. This digital tool also includes a proximity relay, placed in the sheepfold, allowing remote retrieval of mounts data and communicating with a server with a web interface. The Ovimate application enables:
• centralisation, display and post-processing of data issued from the harnesses;
• communication between users (researchers, artificial insemination centres, farmers)
• and configuration of the entire system (Figure 4.4 A).

From a practical point of view, this tool is intended to be combined with the natural "male effect" technique. The males are brought into contact with the females after at least two months of separation, which makes it possible to induce estrus naturally out of the natural season. In this way, the Ovimate tool can determine the kinetics of estrus onset after a "male effect", in order to establish with a high level of accuracy the best time for inseminations to be carried out (Debus *et al.*, 2019). Its design principles offer opportunities for complementary use of the tool in the field of breeding management with:
• the determination of male sexual motivation in an accurate and timely manner (factor 1 to 50 compared to the current method; Alhamada *et al.*, 2017a);
• use as a method for pregnancy diagnosis (Alhamada *et al.*, 2017b);
• and the creation of lambing schedules.

Work on the electronic estrus detector Ovimate has revealed that an essential condition for the success of innovations associated with these technologies is the availability of an infrastructure capable of supporting these applications, such as the INRAE Transfert innovation support system INRAE Transfert, from the optimisation of the technical performance of the sensors to the fulfilment of the return on investment objectives. However, in the agricultural sector, the quality of these infrastructures is still varied.

15. http://www.sheepnet.network/fr.

From the invention of a digital tool to its adoption by end-users, the path of technological innovation involves a set of different stakeholders, skills and interests. The development of the detector took many years (Figure 4.4 B). This is not due solely to the time required to optimise the technical performance of the tool.

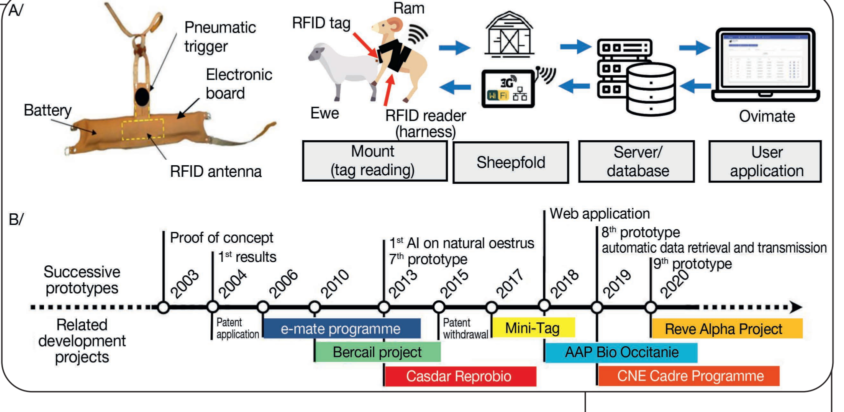
Initially, the acceptability of the solution was negatively impacted by the constraints linked to its implementation and practical use, but also by the perceived impact of its adoption on work organisation (Lurette *et al.*, 2016). Moreover, the commitment of private partners to the project depends on a variety of factors which are difficult to predict: changes in societal expectations, changes in legislation, changes in site policies (closure of the electronics branch of the first company involved, significance given to organic breeding by artificial insemination centres) and budgetary guidelines aimed at meeting the needs of the sectors.

The involvement of end-users is still central to the success of this innovation, even if it was late in the development cycle. The use of surveys of future users and modelling is also extremely important to promote the acceptability of the solution. It enables to anticipate, through simulations, the impact of the introduction of the tool on the various components of the farming system (biotechnical, economic, environmental). It also enables:

- the initiation of discussions with the stakeholders,
- the identification of possible points of tension and support requirements,
- the confrontation with various stakeholders in the sectors concerned.

The joint preparation of scenarios can lead to agreement and easier adoption of the tools and the means of introduction.

Figure 4.4. A. the electronic estrus detector Ovimate. B. its development history.



AI: artificial insemination.

An automated walk out weighing platform for sheep during grazing

Live weight (LW) is the measurement used to monitor the body condition of animals on a frequent basis and for general herd management, e.g. to control feeding, to assess weight gain, health and meat value or to establish slaughter schedules. In free-range systems with confined animals, this measurement is relatively simple, although time-consuming and laborious. Conversely, measuring and recording live weight in grazing conditions is a challenging task involving restraining the animals, but live weight is an essential parameter requiring regular monitoring. To overcome this difficulty and to feed research into the adaptive capacities of animals under constrained conditions, a prototype automated weighing system for small ruminants was designed and tested.

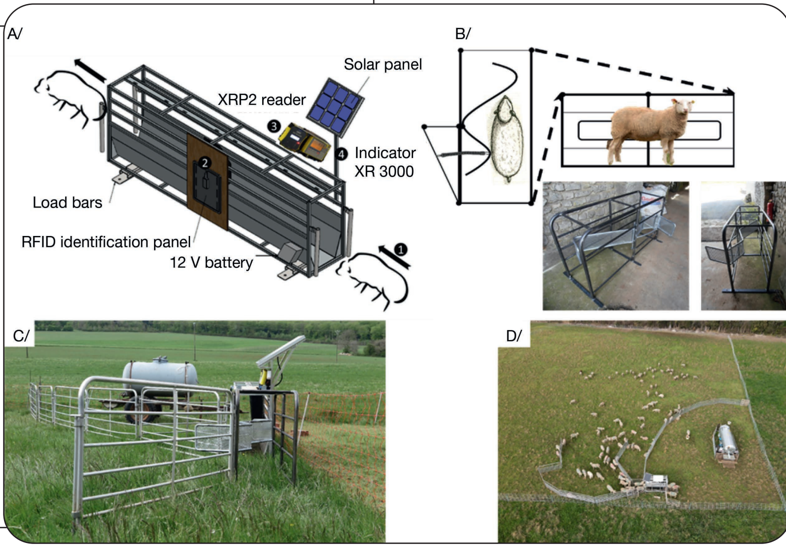
To achieve this, we used the concept of automatic (Walk-over-Weighing, WoW), combined with radio frequency electronic identification. The WoW was designed to be lightweight, durable, transportable and energy self-sufficient (González-García *et al.*, 2018).

The device consists of a lightweight, removable, portable lane equipped with two loading bars (weighing bars), a system for reading and remote transmission of the animal data and a power plant (solar panel and battery; Figure 4.5). Module S, located at the entrance to the WoW facilitates the flow of animals one at a time and prevents the clumping of several animals simultaneously. A voluntary one-way flow is established.

Since the end of 2015, a series of successive and complementary steps have enabled the calibration and evaluation of the device. Practical and theoretical elements related to the effectiveness of the system were validated in a series of experiments with a range of livestock situations (indoor and outdoor, intensive or extensive, animals of various categories, dairy or meat breeds). The adaptation phase (time required for individual passages to be voluntary), the number of daily visits and the proportion of biologically valid and interpretable LW records were analysed on each occasion. Extensive statistical analyses were required to establish the precision, accuracy, repeatability and agreement between the LW recordings with the WoW and the measurements taken with the fixed or static scale (Lin's concordance correlation coefficient, Bland and Alman method).

The main results obtained (González-García *et al.*, 2020b) were used to ascertain the accuracy of the weighing. After eliminating outliers, we obtained a high level of agreement between the two methods (LW WoW and fixed LW) and obtained excellent indicators of repeatability, reproducibility, precision, accuracy, agreement, compared to the so-called "gold-standard" method (fixed or static scale). In all the experiments developed so far, we obtained 65% of reliable (valid, usable) LW WoW readings and validated the effectiveness of the S module to control the flow. Training and adaptation of the animals is successful in 2-3 weeks. The voluntary passage enables the collection of 6 to 8 interpretable LW values per animal per day. The "logical" circuit is successful and the effectiveness of the area of attraction is demonstrated (role of water, mineral salts, shade from trees).

Figure 4.5. Self-weighing platform.



A. the animal (1) the animal voluntarily moves across the platform, drawn to an area of attraction on the other side (water, mineral salts, shade from trees); (2) the antenna reads the animal's electronic identification tag (EID) (located on the left ear) and sends the animal's EID to the reader; (3) the reader records the EID in a file and sends it to the indicator; (4) the indicator records the live weight of the individual and the date and time of weighing when the animal left the platform. The operator downloads the stored files (CSV or XLS format) for further processing and interpretation. B. animal flow control device (S-shaped metal structure) placed at the entrance to the WoW unit. C and D. overviews of the device installed in a variety of grazing systems and field conditions. The partners involved in its design are various: INRAE and the Selmet research unit, the project leader; the INRAE experimental field at La Fage (France), the experimental unit where the work took place; Marechale Pesage, a private company that manufactured the prototype; and the Institut d'Élevage (Idele) for distribution to producers.

Static weighing, the technology available to date, requires the retention of concentrated and stressed animals. However, the WoW allows voluntary, frequent and automatic weighing of animals without operator intervention. Such automatic and continuous monitoring of the animals LW therefore contributes to the monitoring of the body condition of the herd. It is a decision-making tool for the farmer and advisors, allowing adjustments to be made to feeding practices. Finally, the WoW has attracted the attention of producers and has reinforced our research on feed efficiency and adaptive capacities in the field.

Wiktrop, a collaborative web portal dedicated to weed management in tropical and Mediterranean cultivated and grazed land

In livestock grazing systems and harvested pastureland the development of weed species spares no region of the world and represents a challenge for the productivity and sustainability of this systems. Depending on their harmfulness and their "unpalatability" to livestock, they can degrade the resource by competing with forage species and in extreme situations may even make them disappear. These species can also become a threat to the biodiversity of natural environments by colonising them. Finally, some species can be toxic, posing a risk to animal and human health.

Livestock grazing systems (and agriculture in general) are at the origin (voluntary or involuntary) of many introductions and disseminations of more or less invasive species, but they are also one of their main victims. Within the framework of the agroecological transition and in order to cope with global changes, having tools to help regulate these species is a research and development challenge to better manage biodiversity in agroecosystems. This approach notably requires the availability and use of extensive data on the biology of species and their behaviour. The management of this information has been the subject of renewed interest over the past ten years, going beyond the classic top-down transfer of technical information developed in "weed science". Since 2010, the capitalisation and dissemination of scientific knowledge have benefited from innovative approaches based on the (open data) approach. The consolidation of information is strategic and constitutes a field of research in its own right with the development of approaches based on new information and communication technologies such as text mining and the knowledge management system(KMS) (Talib *et al.*, 2016; Girard *et al.*, 2017 in Le Bourgeois *et al.*, 2019).

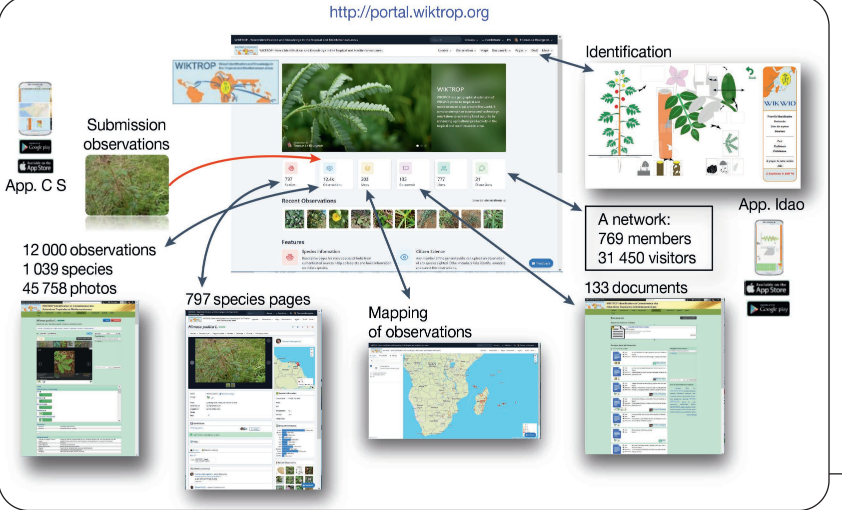
Wiktrop, for Weed identification and knowledge in the Tropical and Mediterranean areas, is a digital tool directly resulting from this technological evolution. It is defined as a collaborative web portal for sharing and distributing information on weed management in tropical and Mediterranean cultivated and grazed environments (Figure 4.6). In addition to its species identification function, it is aimed at developing a multi-stakeholder network of researchers, extension agents, teachers, academics, citizens and farmers. The aim is to consolidate existing scientific and technical expertise and facilitate its sharing.

The aim of the portal is to provide a participatory digital agriculture approach where users are called upon to contribute to the knowledge sharing process by posting information, documents, species observations and discussing issues and solutions with other users in the network. The philosophy of this portal is to bring together expertise from research, civil society, information technology and environmental law.

In 2014, based on this horizontal approach, a first collaborative portal was launched on crop weeds in the Indian Ocean (Wikwio for *Weed identification and knowledge in the Western Indian ocean*). It was developed by combining several pre-existing technologies: the I*ndia Biodiversity Portal*[16] and Idao (computer-assisted plant identification) developed to facilitate plant identification (Le Bourgeois *et al.*, 2008; 2019). This first portal was bilingual, and was then combined with mobile applications for collecting

16. http://indiabiodiversity.org/.

Figure 4.6. Wiktrop collaborative portal.



The portal (http://portal.wiktrop.org) consists of: (i) a computer-assisted plant identification tool (Idao) accessible to non-botanists; (ii) an interface for posting observations and identification requests/confirmations via photographs; (iii) a documentary database of around 800 species; (iv) a system for mapping weed observations; (v) an exchange interface by type of agricultural production. The functionalities are available on PC and smartphone (Wiktrop on Google Play). The know-how, data, information, media and documents are distributed on the portal under a Creative Commons license (CC 2017).

field observations and field identification. Training sessions for producers, agronomists, supervisors, teachers and students were accompanied by a survey to analyse the feedback. Since 2017, the portal has been extended to other tropical regions (Oceania, Central and West Africa, Guyana, Asia, etc.) under the new name Wiktrop. Its range of use has been extended by integrating livestock grazing systems and harvested pastureland from an Idao tool on weeds and conflict plants in New Caledonian grazing lands (AdvenPaC; Blanfort *et al.*, 2010).

Full integration into the grazed ecosystems portal is still in progress, but the hindsight of a few years of use in the crop domains has made it possible to draw some lessons. Although the majority of Wiktrop users consult the portal, the process of sharing data, information or knowledge is still insufficiently implemented, or even refused, in particular by scientific and technical stakeholders. The quality and interest of this portal therefore depends on a better appropriation by the stakeholders of this "sharing" dimension, by developing the mode of use and contribution.

⁂

This research work highlights the originality and specificities of inventions to contribute to the agroecological transition in livestock farming to:
• manage livestock systems with fewer synthetic inputs;
• obtain regular and rapid information required for the complex management of Mediterranean and Tropical agropastoral livestock systems;
• better use and manage available forage resources and grass cover.

These inventions contribute to the emergence of more efficient farming systems by promoting co-creation and knowledge sharing.

The technical innovations that we describe in the rest of this chapter focus more on the recycling of biomass and the diversification of forage resources in production processes, which are at the heart of research on the agroecological transition.

Technical innovations to improve recycling and diversification of resources in livestock grazing systems

Mélanie Blanchard, Ollo Sib

Improving the closing of biomass and nutrient cycles and diversifying resources from agroecosystems are two pillars of agro-ecology, in which ruminant farming can play a key role. This is because, through their ability to consume fibrous feeds (e.g. grass and straw) and by-products and wastes (e.g. swill), ruminants use biomass that humans cannot eat, thereby increasing the efficiency of natural resource use. However, although numerous studies conducted in research stations have shown how agroecology allows for greater production while minimising negative externalities (environmental, social, economic), the adoption rates of these practices often remain limited and underline the relevance of better supporting stakeholders in adapting their practices to this new paradigm according to the local characteristics of their livestock system. This section of the chapter illustrates this through the presentation of two case studies, from tracking down innovative practices to measuring the first impacts using participatory co-design mechanisms.

Shrub fodder banks, a promising innovation for agro-pastoral dairy systems in West Africa

In West African agropastoral systems, the milk productivity of cows remains low and irregular, partly due to the low coverage of their nutritional needs during the year. Cow feeding is essentially based on a combination of:
• natural grazing land with low and seasonal quality biomass productivity,
• and crop residue, grazed in the field or stored on the farm, mostly composed of straw with low nutritional value.

In order to intensify milk production to meet the demands of dairies and consumers, some farmers have adopted fodder crops (grasses) to complement these resources.

Others have resorted to expensive and unaffordable concentrate feeds, the heavy use of which poses potential health risks for the animals. The search for alternative options to fill the existing gaps in feed and productivity is a priority for farmers, dairy value chain stakeholders and research and development. The alternatives to be promoted must be productive, sustainable and affordable for low-income farmers in order to enhance their farm autonomy.

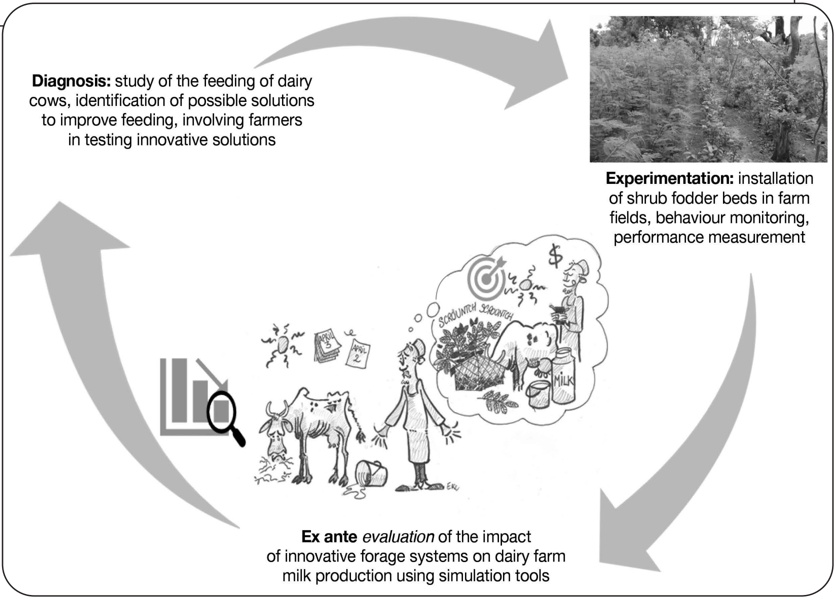
A promising alternative, tested in several humid tropical regions (Latin America, Oceania, the Caribbean, Asia, etc.) is based on agroforestry-livestock integration. It consists of introducing various strata and species of multipurpose trees and shrubs at different densities into livestock farms for livestock feed.

In the context of the West African savannahs, the role of spontaneous fodder trees and shrubs in feeding livestock in the dry season is well documented. In the natural environment, the sometimes over-intensive use of branches and twigs of fodder trees and shrubs (Kaya senegalensis, Pterocarpus erinaceus, etc.) to feed livestock leads to a decrease in the resource. Agroforestry, through the technique known as high-density shrub fodder banks, is an interesting solution. It makes it possible to intensify quality fodder production in order to improve fodder autonomy, reduce the dependence of farms on concentrated feed, increase the production and income of farmers and improve plant and wildlife biodiversity on farms. In addition, due to the richness of woody fodder in proteins and tannins, the shrub fodder reserve is an option to ensure a protein supply to animals, limit greenhouse gas emissions and strengthen the resilience of livestock systems to climate change.

The idea of introducing high-density shrub fodder banks (20,000 plants/ha) into agro-pastoral systems in western Burkina Faso was born out of partnership projects between UMR Selmet and the professional organisations with which it has been working for years on crop-livestock integration issues. This initiative aimed to meet the demand of livestock farmers in western Burkina Faso for sustainable and low-cost intensification of local milk production.

The introduction of shrub fodder banks was based on an iterative co-design process in order to adapt them to the multiple technical and socio-economic constraints and to the local knowledge of the farmers (Sib *et al.*, 2020; figure 4.7). Farmers and stakeholders in the sector took part in the initial diagnosis of livestock systems by means of individual surveys and group feedback to identify animal feeding practices on the grazing land, according to the seasons, and to analyse possible solutions for improvement. The shrub fodder reserve was presented as a potentially interesting solution, and volunteer farmers agreed to try it out on their farms. To support these farmers in learning this new technique, a consultation framework was set up at each site and led by the research team, the farmers, the decentralised technical services, the local communities, the customary authorities and the dairies. The participatory workshops gradually provided an opportunity to acquire the theoretical principles of shrub fodder reserves and to adapt the innovation to the local context and the farmers constraints.

Figure 4.7. Co-design process of an innovation consisting in the introduction of shrub fodder banks in dairy agro-pastoral systems in western Burkina Faso (source: Ollo Sib).



The shrub fodder bank contributes to the diversification of the fodder system of dairy farms and to the improvement of their fodder autonomy, with over 10 tons DM/ha/year of quality fodder (gross protein › 20% DM). It contributes to their resilience in the face of constraints on access to natural grazing land, better nutritional quality of dairy cow rations, with dry matter and organic matter digestibility between 65 and 81% and increased cow productivity (+ 1 or 2 litres per cow per day) while potentially reducing enteric methane emissions.

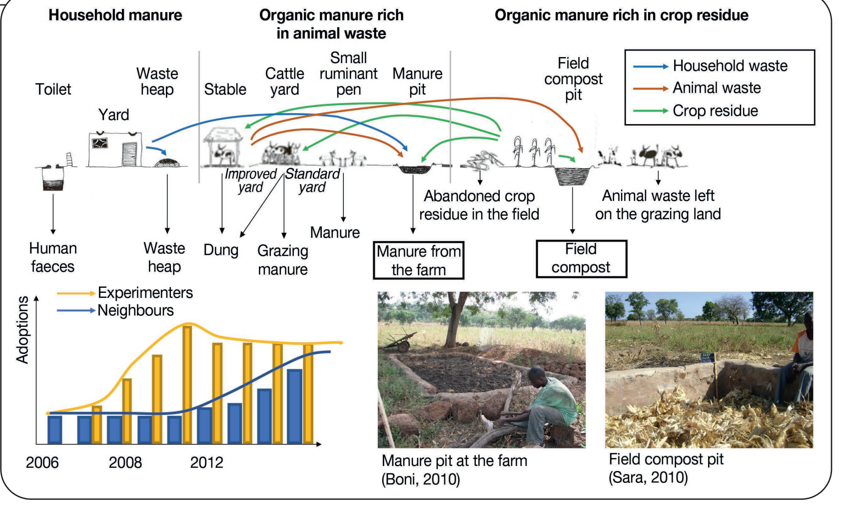
“From tracking to impact” of innovative organic manure management practices in agro-pastoral systems in western Burkina Faso

The decline in soil fertility in the West African savannahs jeopardises the sustainability of production systems in a context of increasing population, cultivated areas, livestock farming and pressure on natural resources. In western Burkina Faso organic manure production techniques have not been widely adopted due to transport and labour constraints and subsidies for mineral fertilisers. A small proportion of agricultural and livestock co-products were valorised and the manure produced remained of poor quality.

The co-design of innovative practices (Vall *et al.*, 2016a) was initiated to quantitatively and qualitatively improve the organic manure produced in this area. The approach began with a problem-solving phase involving the study of soil fertility management issues with the stakeholders involved in order to identify the desire for change on the part of the stakeholders and the intention to research innovative practices.

A step-by-step design of innovations was initiated (Figure 4.8). Studies of local knowledge on soil fertility management in southern Mali (Blanchard *et al.*, 2013) and atypical practices in Burkina Faso (Blanchard *et al.*, 2017) have made it possible to identify a body of original and local technical knowledge on soil fertility management and the recycling of agricultural and livestock co-products requiring little investment. These studies made it possible to identify possible solutions for improving soil fertility management. The innovation proposed to Burkinabè farmers aimed to increase the production of organic manure by distributing it across the farm using a manure pit and a compost pit at the edges of the fields. The most popular options were tested on the station and with volunteer farmers. The technical procedures for ensuring compost quality while minimising labour investment (chopping cotton stalks, watering, and turning) were defined at the site. More than 1,200 experiments at and by farmers have made it possible to evaluate the quality and performance of manure pits and compost pits in real-life situations. Finally, trials on the rational application of manure in the field have made it possible to quantify the impact of different application methods on yields

Figure 4.8. The diversity of organic manure management practices on farms and two innovative models available for adoption: the manure pit and the field-side compost pit.



and economic performance. After each experimental cycle, the results obtained were discussed in order to decide on readjustments, the organisation of new experiments or, on the contrary, the closure of the design process if the objectives were achieved.

To implement this approach, specific partnerships were formalised. Farmers wishing to change their practices, agricultural advisors in charge of farm supervision and researchers formed village committees, these were in charge of leading the process and implementing the activities. A steering committee made up of representatives of research and development institutions and producers decided on strategic orientations, validated programming and managed any arbitration. An ethical framework and governance bodies defined the roles and responsibilities of everyone in this co-design phase (Vall *et al.*, 2016a).

Multi-pit organic manure production improves the recycling of farming by-products by dividing production between the yard and the field. It ensures the quality of the manure and compost produced, without significant investment in equipment, transport and labour. It does not involve watering, chopping of cotton stalks or turning, if decomposition starts in the rainy season and if the pits are covered, for a 12-month production cycle.

Manure is produced from stabled animal manure, mixed with fodder rejects and household waste. The compost is produced by decomposing cotton stalks, otherwise burnt, and a little animal dung to start the decomposition. Recommendations were made for manure production to ensure good quality (minimum dung content, pit coverage) as well as for its application in the field depending on the quality of the manure (compost versus manure). Monitoring the implementation of this process on the farms and an ex post impact study (Vall *et al.*, 2016b) provided insight into the adoption of the innovation and its impacts. The innovation had a positive effect on the farm economy (gain between 21.2 and 51.3 €/ha), soil fertility maintenance (11 tDM/ha compared to 5 previously), animal stabling, but also an increase in labour (installation, production, emptying, transport) and pressure on co-products with the creation of manure markets.

During this adoption process, farmers adapted the proposed practices to their own production capacities, notably by adjusting the size of the pits to the quantity of available co-products, by backing it up with a cattle pen or a bio-digester. Adoption has been sustained and even increased after the project was interrupted, (Vall *et al.*, 2016b) with neighbouring farmers of those who had participated in the project also adopting it. The sharing of know-how was based on village committee networks, highlighting the importance of formalising the partnership in innovation design processes.

⁂

These case studies illustrate various ways of enhancing the local know-how of livestock farmers in the management of their agrosystem resources, noting their contribution to the closing of cycles for the maintenance of soil fertility while limiting the mobilisation of capital, and strengthening the place of trees in fodder systems through the application of agroforestry principles in family-run farms. While this research makes it possible to produce information on the local skills of farmers, their habits and their determinants fairly quickly, it generally takes longer to contribute to changes in practices, as was shown in the work on organic fertiliser.

While the technical nature of the innovation generally signals a change in the mode of production, this change is always associated with the organisational (and sometimes institutional) changes necessary for the distribution and appropriation of the innovation by its users.

Organisational innovations to support the agroecological transition in territories and animal product value chains

M'Hand Fares, René Poccard-Chapuis, Éric Vall

The creation of a favourable economic and political environment is a necessary condition for the implementation of an agroecological transition in livestock systems. At the level of animal product sectors and value chains, this implies a shift towards economic systems that take greater account of the values of the circular economy in exchanges and solidarity between stakeholders. At the territorial level, this implies the implementation of a more sustainable governance of the management of agro-sylvo-pastoral resources. These changes are based on organisational innovations that mobilise stakeholders in the livestock sector and related sectors. This section of the chapter will present some supporting work:

- European livestock owners and farmers wishing to enter into contracts on new forms of crop and livestock interaction in a given territory;
- stakeholders in the dairy sector in West Africa;
- stakeholders in a West African territory who are committed to formulating a local land charter for resource management;
- and stakeholders in the livestock sector in the Paragominas region of Brazil committed to collective action to restore grazing resources.

Organisational innovations to improve stakeholder cooperation in livestock product value chains

Co-design of formal contracts for grazing in cultivated fields

Grazing cereals intended for grain harvesting or vegetation cover as in viticulture at the end of winter is an ancient technique practised in several regions around the world (Canada, Brazil, Australia, the Mediterranean basin, etc.). Abandoned in Europe in the middle of the 20th century as a result of the massive introduction of synthetic input into agriculture, it has been the subject of renewed interest in recent years on the part of certain farmers and livestock farmers faced with climate change and the need to reduce the use of inputs, notably chemical. For farmers, it is a welcome additional fodder resource, in particular to increase their fodder autonomy; for growers, grazing cereals or plant cover has the advantage of reducing weed and disease pressure and the risk of rotting, but also of fertilising the soil and energising the plant thanks to grazing stress.

Within the framework of the European research project H2020 DiverImpacts[17] on crop diversification, a farmer's association (the producer's college) and the Centre de Recherches Agronomiques en Wallonie (CRA-W) on the one hand, and Copyc (the sheep commission of the central Pyrenees), which manages development projects for farmers in the Occitanie region on the other hand, contacted us (Selmet unit, INRAE) to develop a contract between livestock farmers and crop farmers committed to agroecological practices on the same territory. Faced with the development of informal contracts (verbal agreement), the stakeholders in the sector wanted to introduce more formal grazing contracts (in writing) in order to secure the existing relationship and strengthen the cooperation between farmers and livestock farmers. As these formal contracts are quite new, we worked with the stakeholders to develop an experimental method for their design.

The Discrete Choice Experiments method is an experimental method for evaluating environmental practices (Hanley *et al.*, 2001). Contrary to other methods, it can be used to assess innovative systems that are not, or are only marginally, distributed to stakeholders. In the agricultural field, this method has recently been applied to organisational innovations such as agri-environmental contracts (Mamine *et al.*, 2020).

The aim of this method is to reveal the preferences of stakeholders confronted with an innovation, through an experiment in the form of a questionnaire consisting of choice cards. The most difficult part of the design process of this experiment is the definition of the optimal number of cards representing, in our case, the most relevant attributes or dimensions of the contract between livestock farmers and cultivators.

The implementation of a co-design process within a focus group, composed of experts and stakeholders in the contract, meets this constraint. The use of a Product Service Systems (PSS) approach also enabled us to specify:

- the various types of ecosystem services rendered by the introduction of sheep used as substitutes to the use of chemical (or mechanical) inputs in order to eliminate the vegetation cover (intermediate crops or weeds) of a cultivated field (Mamine and Fares, 2021);
- and contractual dimensions crucial to the relationship such as duration, monetary compensation between livestock keepers and farmers, the formal or informal nature of the contract, the size of the herd, the composition of the crop cover, etc. (Figure 4.9).

Once this experimental contract was co-designed, we tested its validity on a larger population of individuals. We conducted a survey of 10 livestock and crop farmers in Wallonia (5 cereal farmers, 5 livestock farmers) and 7 in Occitania (3 cereal farmers, 2 winegrowers and 2 livestock farmers).

17. http://www.diverimpacts.net.

Figure 4.9. Co-design of a formal contract between farmers and livestock owners in the framework of the Diverimpacts project (Collège des producteurs, Wallonie recherche CRA-W, Copyc, Selmet).

Example of a map selection

Choice Card #1	Alternative 1	Alternative 2	Alternative 3 (*status quo*)
Contract duration	1 year	2 to 3 years	Over 5 years
Compensation	In favour of the livestock farmer	In favour of the crop farmer	No compensation
Formal contract	On behalf of the livestock farmer	On behalf of the crop farmer	No formal contract
Commitment to Grazing schedule	Fixed dates	Variable dates	Schedule according to plots
Herd Size	Maximum	Minimum	Maximum and Minimum
Composition of the plant cover	Species to be included	Species to be exclude	Species to be included and excluded
Note your alternatives Order preferences from 1 to 3	...	...	...
Tick one of the three options	☐	☐	☐

The results of our experiment of choice demonstrate that the barriers to adoption are not so numerous, contrary to other systems (Meynard *et al.*, 2018), and that a form of cooperation can emerge because both the farmer and the livestock producer have a joint interest. The co-design process of a formal contract is nevertheless of interest because it strengthens the development of cooperation between the stakeholders. A significant preference for more formal contracts can be observed, since 90% of the people surveyed would prefer long-term contracts (> 1 year), 60% prefer written contracts, etc. These clauses make it possible to secure the existing relationship between both parties and to base cooperation on a long-term relationship, even if these formal contracts do not necessarily give rise to monetary compensation between the parties or a firm commitment either to the grazing area/schedule or to the herd size.

There are however regional differences in the contracting choices. In Occitania, there is a preference for short-term contracts. Similarly, in particular in the wine production sector, there is more often a formal commitment to a maximum herd size or grazing schedule, as well as a request for a guarantee on the status of the food resource (before the animals pass through) or, failing that, monetary compensation.

The resulting formal contract must be seen as an organisational innovation that supports the development of innovative agricultural practices, both on the part of the farmer (introduction of a diversified low-input system) and on the part of the herder (new form of transhumance and grazing of his herd). Certainly, the formal contract ensures the credibility of the commitments between the two partners and thus the emergence of a sustainable cooperation, which allows them to benefit over time from the mutual exchange gains generated by these innovative practices. In other words, innovations in practices and organisational innovations go hand in hand and must therefore be thought out jointly to ensure the agroecological transition.

Innovation platforms to improve local milk production and collection in sub-Saharan Africa

Currently, in sub-Saharan Africa, the demand for dairy products is increasing due to population growth and the emergence of a middle class. Many milk processing units are opening. However, these dairies face difficulties in sourcing local milk. These difficulties are related to volume, regularity and quality. Their supply is affected by multiple constraints such as the low milk yield of local cows, the seasonality of production, the fragmentation of production among small farms, high collection costs and the degradation of the microbial quality of milk during transport to the dairy. The use of milk powder is common, either temporarily during periods of shortage of local supply (dry season) or, and this is often the case, throughout the year.

In this context, a research project[18] was conducted to support the co-design and implementation of technical and organisational innovations to increase and secure local milk supply, taking into account the potential for agroecological intensification of milk production and the development of efficient and inclusive collection systems.

For innovation design, the project relies on dairy innovation platforms (DIP). A DIP is a mechanism that unites dairies, milk producers, collectors, the agro-industry, stakeholders in the dairy sector and researchers who want to find solutions to the problems encountered in the production and marketing of local milk.

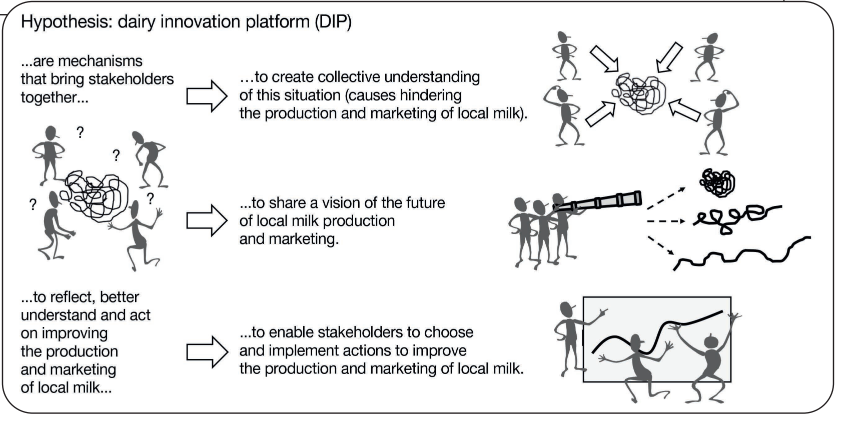
DIP stakeholders are at the heart of a challenging situation, which they strive to understand (search for intelligibility), whose possible developments they would like to foresee (search for predictability) and among which they aim to implement options chosen to guarantee the sustainability of their activity (search for feasibility) (Figure 4.10).

A board is elected to coordinate DIP and to distribute the workload, it is led by a coordinator. Research, which has no apparent conflict of interest with DIP stakeholders, provides methodological and scientific support to organise the participation, study milk production and marketing systems and provide simulation tools.

Six DIPs in 3 countries - Senegal (2 DIPs), Burkina Faso (2 DIPs) and Madagascar (2 DIPs) - have been set up. Depending on the case, the DIPs involve either a dairy or the dairies in the intervention area. The dairies are of differing sizes (including both mini-dairies with less than 500 l/d and industrial dairies with over 11,000 l/d).

18. Africa-Milk Project, http://www.africa-milk.org/.

Figure 4.10. Dairy innovation platforms and the questions they address through collaboration between dairy industry stakeholders and researchers.



The analysis of the initial situation is based on a diagnosis of the status of milk production systems and the milk collection system (mapping of the collection basin, study of the supply chain and collection practices, identification of local milk production and marketing issues).

Local stakeholders generally have an ongoing strategy and actions to improve milk production and marketing (installation of mini-farms in Senegal, establishment of collection centres in Burkina Faso and Senegal, improvement of milk quality control in Madagascar, establishment of milk payment systems linked to quality in Kenya, etc.). However, they sometimes have difficulty agreeing on the implementation of a strategy that reconciles the interests of all parties (producers, collectors, processors). To develop a collective vision of the future, we use modelling tools (multi-stakeholder territorial simulation tools, Cesaro, 2021; CLIFS: Crop livestock farm simulator; Le Gal, 2021; Zoungrana, 2020) to develop scenarios and discuss model outputs with DIP stakeholders during scenario-building workshops.

Local stakeholders join the DIP mainly to improve their income from milk and dairy products. The study aims to support them in this perspective, while reflecting on the implementation of environmentally friendly (green business) and inclusive (social business) practices, with a equitable distribution of the added value (fair business). It is with regard to this type of concern that participatory methods and scenario-building tools greatly facilitate interactions between stakeholders in the dairy sector (who generally interact very little) and anticipation and projection exercises for their activity in the future. DIP facilitates the inclusion and consideration of the concerns of stakeholders who are often marginalized in value chains, such as women milk producers and young people.

In theory, DIPs are invested with multiple qualities (participation, inclusion, sustainable development, etc.) (Davies *et al.*, 2016), Ibut in reality, because the stakeholders who join do not all have the same interests, do not all speak the same language, and because there are situations of significant imbalance between the stakeholders, and because it is never easy to overcome one's own prejudices, they require a great deal of effort in terms of facilitation in order to create trust between the stakeholders, a trust which is the basis for producing the expected effects. In other words, it takes time and a lot of energy, know-how and diplomacy to achieve a result. Research is often at the origin of the setting up of such schemes. But experience shows that it is crucial for the success of a platform that field workers acknowledged by their peers assume the role of facilitator, so that all the stakeholders involved adopt the system.

Ultimately, DIPs are of interest to field stakeholders and to research, as a meeting place between a commitment to change (on the part of stakeholders) and a research intention (on the part of scientists). In our research on the agroecological transition in livestock grazing systems, DIPs can also be considered as living-labs. They enable both the testing and development of innovative farming practices and systems and the bringing together of concerned stakeholders to discuss the necessary adaptations to enable the appropriation of the innovations required by the stakeholders and their scaling up.

Organisational innovations for concerted and sustainable management of territories incorporating livestock activities

A local land charter for sustainable management of agro-sylvo-pastoral resources: the case of the commune of Koumbia in Burkina Faso

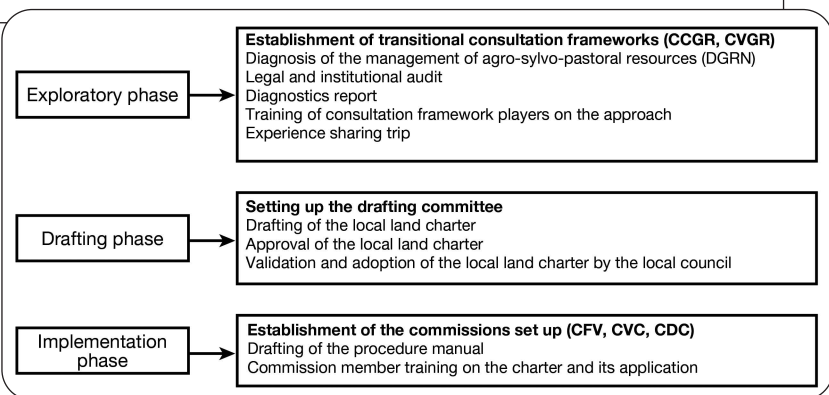
In the western territories of Burkina Faso, as long as human pressure remained low, customary rules ensured the sustainable exploitation of natural resources. However, the unprecedented increase in population and agro-sylvo-pastoral activities in these territories has rendered these traditional arrangements obsolete. The official texts (forestry code, environmental code, pastoral code, etc.), which were not well known by the populations, were not applied. The establishment of rural communes in 2006 and the enactment of Law 034 on rural land tenure in 2009 gave local communities the opportunity to take charge of the management of their agro-sylvo-pastoral resources by drawing up local land charters (LLC).

The rural commune of Koumbia, located in the heart of the cotton-growing zone, consisting of 14 villages on 1,358 km² of savannah (30% of which is protected forest), where crop and livestock farming are the two dominant activities, and which has seen its population triple over the past few decades, has been calling for measures to curb the degradation of its resources and the rise in conflicts related to their use. In 2008, the Koumbia communal council, which had included the implementation of measures to regulate the use of the commune's natural resources in its development plan, seized the opportunity of a research and development project (Fertipartenaires, 2008-2012) to be supported in the development and implementation of an LLC (Vall *et al.*, 2015) in order to define rules for access and use of resources that are adapted to the local context, in line with the regulatory framework, and acceptable to resource users in their diversity.

The development of the LLC took two years (2008 to 2010) and required multiple negotiations between stakeholders at different decision-making levels (village, commune, province). During this process, several groups of stakeholders took part in drawing up the LLC: local elected representatives and village development councils, users (farmers, livestock owners, fishermen, hunters, loggers, etc.) - both indigenous or non-indigenous, often organised in groups - institutional stakeholders (technical departments responsible for the environment and the living environment, agriculture and livestock, etc.), private operators involved in exploiting resources (hunting concessions, gold miners, etc.), research (Cirdes and CIRAD) and a legal firm specialising in the environment.

The development of the LLC, which is based on principles of participation and inclusion, involved three main phases: the exploratory phase, the charter drafting phase and the implementation phase (Figure 4.11).

Figure 4.11. General approach to the development of the Koumbia local land charter.



CCGR: community-based natural resource management.
CVGR: Village natural resource management committee.
CFV: village land commission.
CVC: village conciliation commission.
CDC: local conciliation commission.

At the end of this process, the communal council of Koumbia adopted the LLC in 2010. It contains 56 articles divided into 7 chapters:

1. General provisions
2. Access to land
3. Management of agricultural, hydraulic and fishery resources and spaces
4. Management of grazing areas and resources
5. Management of forestry and wildlife areas and resources
6. Bodies responsible for the implementation of the LLC
7. Final provisions and implementation modalities

The fourth chapter of the LLC, which deals with grazing resources, includes 14 items on the rules of access to and use of grazing resources (grazing land, water points, traffic routes, fire management, herding...). In these sections, local farmer know-how was taken into account, notably the nomenclature of seasons and grazing lands in Fulfulde, with the aim of improving the comprehension and applicability of the LLC. In an agro-ecological transition perspective, the recognition and valuation of local know-how is often useful to promote the appropriation of results and the change process. The aim of this charter was to ensure that the local nomenclature of seasons and spaces would be more understandable to the local population by designating entities that the population would be familiar with for the management of their daily activities.

But the establishment of the LLC has encountered several issues related to the political crisis that the country went through from 2011 to 2014. The state was unable to install the land agents and was unable to adopt all the decrees for the application of Law 034; the municipal council involved in the development of the LLC was abolished. To date, the LLC, although acknowledged in the official gazette, has not been fully implemented.

The participatory process of co-designing the LLC has made it possible to enlist stakeholders and achieve the adoption of the LLC, through the establishment of consultation committees involving several scales (village, commune and province).

The fourth chapter of the LLC, which deals with grazing resources, includes 14 items on the rules of access to and use of grazing resources (grazing land, water points, traffic routes, fire management, herding...). In these sections, local farmer know-how was taken into account, notably the nomenclature of seasons and grazing lands in Fulfulde, with the aim of improving the comprehension and applicability of the LLC. In an agro-ecological transition perspective, the recognition and valuation of local know-how is often useful to promote the appropriation of results and the change process. The aim of this charter was to ensure that the local nomenclature of seasons and spaces would be more understandable to the local population by designating entities that the population would be familiar with for the management of their daily activities.

But the establishment of the LLC has encountered several issues related to the political crisis that the country went through from 2011 to 2014. The state was unable to install the land agents and was unable to adopt all the decrees for the application of Law 034; the municipal council involved in the development of the LLC was abolished. To date, the LLC, although acknowledged in the official gazette, has not been fully implemented.

The participatory process of co-designing the LLC has made it possible to enlist stakeholders and achieve the adoption of the LLC, through the establishment of consultation committees involving several scales (village, commune and province).

The implementation of new collective rules may be limited by factors operating at a higher scale. This is why the development of the LLC involved stakeholders at the provincial and state levels to ensure that local rules were consistent with national and international provisions.

In the LLC development phase, research provided scientific diagnostic tools (relating to the management of natural resources, analysis of local technical expertise) and engineering tools (management of participation) to support the stakeholders (supplying information and facilitating negotiations).

The implementation of such a device, which affects the governance of a territory, is dependent on numerous contextual elements (notably political, social and regulatory). The existence of a legal framework greatly facilitated the development of the LLC, whereas the events of 2011 to 2014 suspended its application (because following the 2014 revolution, the town halls and municipal councils with whom we had worked were dismissed and the land service agents responsible for applying law 034 never operated in the field). However, by taking into account the local know-how and practice of livestock producers and farmers, as well as their involvement in formulating the LLC's provisions, it was possible to create a document in which they could identify and which made sense to them.

As noted previously, post-2012 events have not permitted the completion of the implementation of the LLC and its effects and impacts over time. However, there are more successful experiences in the Sahel that demonstrate that this type of local organisational innovation can improve the governance of a territory and the use of natural resources (Djiré and Dicko, 2007).

When rotational grazing contributes to forest restoration: a territorial innovation in the Brazilian Amazon

With its 86 million head of cattle reared on 70 million hectares of grazing land, over the past 50 years the Brazilian Amazon has become one of the world's largest livestock basins at the expense of the rainforest. Some renewable natural resources are more abundant than elsewhere, such as solar radiation, rainfall and deep soils. These can sustain high levels of soil fertility and grazing productivity, if the farmer applies appropriate techniques.

However, it is not these agronomic advantages that explain the resounding success of livestock farming, but rather its social functions, which are particularly valuable on the pioneer deforestation fronts. Extensively managed, livestock farming makes it possible to appropriate and develop large areas of land at lower cost, more quickly than other land uses, while overcoming the chronic lack of labour and the lack of infrastructure for the production, marketing, processing and transport of agricultural products. In this way, extensive livestock farming has contributed to the viability of family farms in the Amazonian pioneer fronts (Ferreira, 2001).

However, Hostiou (2003) has illustrated the other side of the coin: extensive practices do not maintain the fertility accumulated in the soil by the forest. The grasslands are then quickly invaded by shrubs and the traditional resort to fire is a remedy worse than the evil: it accelerates the exhaustion of the soil and pushes the farmer to clear more and more land to compensate for the degradation and maintain production (while increasing land holdings). During the fifty years of this race for land, deforestation was routine: forests were mere fertility reserves for ephemeral fodder production.

How do we stop this immense waste of natural resources? How can their agroeconomic potential be used efficiently, without losing the social functions of livestock, to make it a sustainable activity adapted to the Amazonian environment? The case of the municipality of Paragominas demonstrates that such a transition does not only depend on the farmers: the territorial institutions must also be organised.

The Brazilian federal government has set a milestone by preventing deforestation in the entire region from 2005 onwards: the land appropriation function of large-scale livestock farming has been disabled and soil degradation can no longer be compensated for by opening up new plots. The farmer is obliged to manage their resources, at the risk of seeing their production fall. Plassin (2018) subsequently diagnosed a fundamental shift in the spatial strategies of livestock farmers: by abandoning their extensive logic, they now take into account the capacities of the soils, to concentrate their efforts of restoration and forage intensification on the best plots. The other plots, which are too steep, poorly drained or subject to erosion, are gradually cleared: a new forest network can be reconstituted there, capable of once again producing ecosystem services based on biodiversity, the water and carbon cycle, as measured by Pinillos (2021b).

In the municipality of Paragominas, this observation has given a new impetus to forest protection: it is now understood that it is no longer incompatible with cattle ranching, but on the contrary is associated with it. Within the framework of the plan of Intelligence and Territorial Development decreed in 2019, a new territorial policy on livestock farming is being implemented on the basis of two mechanisms: green finance and municipal management (Poccard-Chapuis *et al.*, 2021).

To democratize forage cultivation and increase the scope of landscape restructuring, credit is a valuable lever if it is within the reach of the greatest number of people. The Banco da Amazônia has joined forces with Cirad and the livestock farmers union to design and launch a new line of credit in 2021, dedicated to the ecological intensification of grazing land and focusing on a simple technique that is accessible to all: rotational grazing (Figure 4.12). In addition, for the first time, funding is based on a type of livestock farmer and is conditional to prior training: the aim is to minimize the risk of failure potentially linked to the difficult transition from extensive to managed systems.

The second axis is led by the city council, to draw up a municipal land use plan according to the aptitudes of the environment. Composed of a 1:25,000 scale map and a municipal law, this decentralized regulation is used to precisely guide ranchers in their intensification and reshaping of landscapes, as well as to measure the territory's progress in terms of forest restoration and land use efficiency at the municipal level. A regional label is envisaged to certify this progress in land use planning in a transparent manner and so attract other responsible investors in search of sustainability.

This trajectory of innovation demonstrates the value of multiple iterations based on opportunities, constraints and regulations, to transform antagonistic issues into a shared solution. Livestock development and forest protection together produce efficient landscapes, under the guidance of local governments and with the support of the financial sphere. The communal territory is the level of organisation at which these

Figure 4.12. Rotational grazing technique.

This technique, in which cattle are confined to small pens, with rapid rotation from one pen to another depending on grass growth, is only feasible on the best plots. The consequence of this key innovation is a spatial reorganisation of pastures, with less favourable plots being reforested. A new forest framework is emerging beyond the framework imposed by the law, through the process of livestock intensification. New landscapes have emerged, drawn by the aptitudes of the soil, integrating mosaics of forage parks and a recomposed forestry network.

iterations could bear fruit and lead to this new paradigm for sustainable development in the Amazon. But in order to sustain the interest of industries and investors, the experiment must reach a critical mass and involve neighbouring municipalities: a higher level of organisation must be considered, such as that of communities of municipalities.

⁂

The creation of an appropriate environment for the agroecological transition in livestock production at the scale of territories (responsible governance) and animal product value chains is certainly as important as the development of inventions and innovations of a more technical nature that offer livestock farmers more profitable performances than conventional livestock practices. However, numerous levers need to be activated (setting up infrastructures, organisations, training and financing flows, new regulations, etc.), involving a large number of stakeholders in the innovation system (Figure 4.1); this represents a long-term task. As a result, one of the questions that arises concerns the role of research in these organisational innovation dynamics, which are particularly complex to implement.

Discussion and conclusion

Éric Vall, Mélanie Blanchard, M'Hand Fares

In what way does this research on invention and innovation in livestock grazing systems contribute to the agroecological transition?

Referring to the FAO's Agroecology Values Grid (Wezel *et al.*, 2020), the eleven case studies just presented highlight the following contributions of livestock grazing systems to the agroecological transition (Table 4.1):

• Research on inventions is positioned on five values of agroecology, foremost among which are co-creation, knowledge sharing and efficiency, followed by the values of diversity and resilience. The sharing and co-creation of know-how are embodied in objects that combine the expertise and know-how of field workers with the latest digital advances for more efficient management of animals, herds and pastoral resources. One of the common objectives of these inventions is to improve the efficiency of herd management and the use of the diversity of resources in livestock agroecosystems (animals, plants, soil, water, etc.). The aim is to avoid overuse and depletion of these resources, without increasing the burden on farmers. This is achieved through:

- rapid access to useful information on resources;
- automated data collection for decision making;
- and tools to reduce the use of synthetic inputs, or even remove them from farming systems (e.g. elimination of hormones through the use of ewe heat sensors).

• Research on the step-by-step co-design of innovative livestock systems, applied to technical innovations involving the recycling of organic manure and the biodiversification of fodder systems, is based on six agroecological values, the most important of which are co-creation and knowledge sharing, efficiency and synergies, followed by the values of resilience, diversity and recycling. In this study, the co-creation and knowledge sharing are conducted in participatory research mechanisms designed to enhance the value of the local practices and expertise of farmers and to involve them in the construction of technical innovations (tree fodder reserves, manure pits at the edges of fields). In the work presented, the objective is more efficient management of the farm's resources (agricultural and livestock co-products, tree plantations, labour) and increased efficiency and resilience to economic shocks (volatility of livestock feed and mineral fertiliser prices), through increased synergies between on-farm livestock and agricultural activities, biodiversification of forage systems and recycling of agricultural and livestock co-products into organic manure.

Research on organisational innovations in livestock grazing systems, both in value chains and in territories, largely reflects six of the values in the FAO agroecology grid. Four of them, namely the co-creation and sharing of knowledge, the enhancement of diversity in the broad sense (resources, stakeholders, etc.), and the strengthening of synergies (between the components and stakeholders of agricultural and food systems), are values common to these case studies. Their mobilisation is intended to bring about the emergence of animal value chains or agropastoral land management systems that are more efficient in terms of resource use and more resilient to economic and environmental shocks. However, a fundamental characteristic of these case studies on organisational innovations is that they take into account other values such as human and social values (inclusion of stakeholders, notably the smallest livestock farmers, minorities and women), responsible governance of territories and collective action through the construction of a solidarity and circular economy at the level of a territory. This reflects the significance attached by these case studies to supporting territorial and sectoral stakeholders in building an environment conducive to the agroecological transition in livestock farming.

Limitations, points for improvement and research prospects for invention and innovation for the contribution of livestock grazing systems to the agroecological transition

The case studies presented (Table 4.1) reveal that research efforts are required on innovations that improve the contribution of livestock grazing systems to certain agroecological values such as recycling (of livestock co-products and effluents such as excreta and GHGs), human and social values (such as issues of inclusion of women and youth in value chains), culinary and food traditions (such as valorisation of local animal products in value chains) and finally circular and solidarity economy (development of value chains related to the valorisation of livestock co-products and strengthening the place of women and youth in the governance of animal product chains).

Table 4.1. Analysis of the eleven case studies through the lens of the ten elements of agroecology defined by the FAO (Wezel *et al.*, 2020).

Elements of agroecology as suggested by the FAO	Part 1: inventions					Part 2: technical innovations		Part 3: organisational innovations			
Case study(*)	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9	EC10	EC11
Case study(*)	×				×	×		×	×	×	×
1. Diversity	×	×	×	×	×	×	×	×	×	×	×
2. Co-creation and knowledge sharing						×	×	×	×	×	×
3. Synergies	×	×	×	×	×	×	×	×	×	×	×
4. Efficiency							×		×	×	
5. Recycling					×	×	×	×	×	×	×
6. Resiliency									×	×	×
7. Human and social values											
8. Cultural and nutritional traditions								×	×	×	×
9. Responsible governance								×	×		
10. Circular and inclusive economy											

Caption: (*) case study headings
EC1. A digital device for studying the social behaviour of sheep and its applications in grazing management and animal health
EC2. Near infrared spectrophotometry to facilitate the determination of forage value and the management of animal manure
EC3. Electronic ewe overlap detector to eliminate the need for hormonal heat synchronisation in artificial insemination
EC4. Sheep self-weighing platform for monitoring the nutritional status of animals with minimal supervision
EC5. Web portal for sharing information on weed management in grazing land
EC6. Shrub fodder banks for improved dry season feeding of dairy cows in Burkina Faso
EC7. Manure pits at the edge of fields to improve manure recycling and reduce workloads in Burkina Faso
EC8. Co-design of formal contracts for grazing in cultivated fields
EC9. Innovation platforms for more environmentally friendly and inclusive local milk production and collection
EC10. Local land charter to manage access and management of agro-sylvo-pastoral resources in the commune of Koumbia in Burkina Faso
EC11. Rotational grazing to help restore forests in the Brazilian Amazon

As regards the distribution of innovative recycling practices in livestock grazing systems, it is essential to develop individual advice tools on good recycling practices at the farm level and modelling tools for innovative collective practice scenarios at the territory level. The modelling work by Grillot (2018a) carried out in West Africa on the agropastoral territories of the Serrer country has revealed the interest of modelling to simulate and better comprehend the effects and impacts of the reorganisation of the nutrient cycle at the territory scale. In 2022, research was also underway in Burkina Faso and Senegal to use models to provide guidance to producers (advice on feeding dairy cows and on the management of agricultural and livestock co-products). These models use little input data and can be used to quickly provide advice adapted to the requirements of producers (quantified advice on the composition of rations including grazing, information on the proportion of unused co-products and advice on how to improve the use of these unused co-products as fodder and manure). In addition, there could be information systems for producers of these farms to help them manage the times and places for spreading manure and slurry according to weather conditions and the topography of the subsoil in order to avoid polluting groundwater and watercourses.

With regard to the implementation of the principles of a circular economy in livestock grazing systems, modelling to support territorial stakeholders plays an essential role in the development of scenarios for the implementation of innovative collective practices based on circular economy schemes. This notably applies to the management of biomass produced by livestock and agriculture in a territory such as on the island of Reunion using the Ocelet software (Vigne *et al.*, 2021a).

The agroecological transition will also depend to a large extent on the downstream part of the supply chains and consequently on consumption patterns. With regard to animal products, consumers, notably urban dwellers, often have high expectations of regaining access to traditional animal products of satisfactory health quality at an affordable price. Adding value to these products will require the implementation of organisational innovations in the traditional livestock sectors in order to meet the new demands for animal products (payment for milk based on quality, for example, geographical indications, etc.).

Finally, the inclusion of human and social values such as dignity, equity, inclusion and justice is not very evident in the case studies presented, even though these dimensions are well present in the current vision of the agroecological transition (Wezel *et al.*, 2020). Women and the young are often more sensitive to the effects of these downturns, and their place and role in the food and farming systems related to livestock and livestock products should be taken more into account (Quisumbing *et al.*, 2014). More agroecological livestock production methods, which often require less financial resources than conventional livestock production methods, can help women in rural areas to acquire more autonomy and power within the household, by giving them the possibility of joining producer groups, women’s trade associations, etc., in order to better maintain control over the sale of their products, such as milk (Valdivia, 2001).

Lessons learnt from the case studies for the design and support of the agroecological transition applied to livestock grazing systems

In the case study presentation, innovations are divided into two main categories: technical innovations and organisational innovations. Technical inventions and innovations were primarily analysed at the animal, herd or production system level, according to the farmer's constraints. Organisational innovations were mainly examined at the level of the value chain or livestock territory to address the issues of farmers, but also of other stakeholders in the territory or value chains. In reality, technical innovations necessarily imply organisational innovations, and vice versa, through a cascade effect. For example, the practice of insemination generates changes in the organisational field of reproduction management. In supporting the agroecological transition, the technical and organisational dimensions of innovation must be taken into account simultaneously.

Analysis of the process of designing technical or organisational innovations in livestock farming confirms the central role of participatory and iterative dimensions. The involvement of the end-user in the design process is essential to adjust, calibrate and test innovations based on the problems for which they are designed and which may evolve over the course of the project. Depending on the stage of development and the characteristics of the innovations, the main stakeholders involved and the methods used in the design cycle differ. Inventions are mainly based on a prototyping stage. The involvement of end-users comes later, when the invention evolves into an innovation. The exploration of solutions can be based on participatory approaches or result from experimentation or similar experiences from research. Experimentation, as practised in the biotechnical sciences, can be complicated and expensive. In the case of new value chains and organisational tools, choice experiments or simulation methods are alternatives to explore a wider range of solutions. The assessment stage is always part of the process, but differs in terms of the object being assessed (innovation, process, impact).

Depending on the characteristics of the livestock systems, these case studies also indicate that the design of innovations often needs to be implemented at different scales in order to capture the relationships between the components of the livestock systems and their environment. For example, herd mobility implies taking into account other territorial resources and activities (multi-use of spaces, multifunctionality of livestock) or the renewal of spontaneous vegetation (rangelands). Livestock systems also involve designing innovations over the long term, depending on the selection time of the livestock and the reproduction cycles.