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Critical factors for crop-livestock integration beyond the farm level: A cross-analysis of worldwide case studies

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ABSTRACT

Despite their recognized agricultural sustainability benefits, mixed crop-livestock farms have declined in the Northern hemisphere. As such, crop-livestock integration beyond the farm level is a promising alternative to this trend, but the knowledge of critical factors and strategies towards its successful implementation is still lacking. We developed an analytical framework to assess the critical determinants of the emergence and outcomes of integration, which helped us understand farmers' collective strategies for reducing integration transaction costs. The resulting framework distinguishes between three types of transaction costs: information gathering, collective decision-making, and operational and monitoring costs. These costs are influenced by several factors: external environment attributes, resources engaged in crop-livestock integration, and participating actors and their arrangements. Application of the framework onto six case studies all across the world (Asia, Europe and America) demonstrated it can be utilized for various projects implemented at multiple organizational levels (farm-to-farm, local groups, and regional levels) over distinct farming systems (conventional and organic). Specific policies should be developed to strengthen social networks through the mutual understanding of such integration benefits, since they play a key role in lowering the costs of information gathering and collective decision-making. A legal framework to establishing a formal contract should contribute to lower long-term monitoring costs, especially when trust among actors developing. Operational costs largely depend on the spatial proximity of farms, but this can be overcome by extending the scale of integration in terms of covered area and number of participants. Here, appropriate coordination by third-party entities is essential, and should be targeted by financial and technical support.

1. Introduction

During the mid-twentieth century, in numerous countries of the Northern hemisphere, agriculture has evolved towards mono-cultural production systems, aimed to maximize yield to satisfy both local and export food demands (Matson et al., 1997). This evolution occurred through accelerated mechanization; increased use of fossil fuels, fertilizers, and pesticides; and globalization of agricultural markets. These changes in farm technology and market conditions allowed for the specialization and enlargement of production (e.g., Björklund et al., 1999; Kristensen, 1999; Aguilar et al., 2015). Since then, stringent environmental regulations, detailed animal welfare demands, and higher product quality standards strengthened this trend by requiring increased expertise from farmers, while the environmental impacts (soil, water and food pollution, etc.) of specialized agricultural systems (Oomen et al., 1998; Horrigan et al., 2002) are no longer accepted by some society members.

Diversified systems, such as integrated crop-livestock systems, promote ecological interactions over space and time between system components (e.g., crops, grasslands, and animals) and allow farmers to limit the use of inputs through development of 1) organic fertilization from livestock waste and 2) diversified crop-grassland rotations to feed animals (Hendrickson et al., 2008; Ryschawy et al., 2017). When well suited to local conditions, such integration improves nutrient cycling by re-coupling nitrogen and carbon cycles (Martin et al., 2016; Lemaire et al., 2014; Ryschawy et al., 2017). It can also generate higher

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economic efficiency by reducing production costs and risks, with regard to market fluctuations (Russelle et al., 2007; Wilkins, 2008). However, the major constraints of on-farm integration are related to the limited farm workforce available, combined with a loss in the skills and knowledge required to optimize both crop and livestock sub-systems (Moraine et al., 2014; Martin et al., 2016).

As an alternative to on-farm integration, several authors (Entz et al., 2005; Russelle et al., 2007; Martin et al., 2016) suggest that integration can be structurally organized at larger scales than the farm, through cooperation among specialized livestock and arable farms. In such an organization, some of the synergies normally provided by on-farm integration can be obtained, but determine much smaller increases in farm workload, complexity of rotations, skills, and infrastructure for the individual farms involved (Regan et al., 2017). Since involved farms have opportunities to develop diversified crop rotations, integrate legumes or grasslands, and apply manure, they can also exploit a diversity of environmental benefits, such as biological regulation of pests and diseases, and improved soil quality (Duru et al., 2015; Martin et al., 2016; Moraine et al., 2016b, 2017). However, there may be several environmental limitations, depending on the level of spatial and temporal integration. These include green-house gas emissions associated with trucking around manure, and mismatches between nutrient supply and demand (Martin et al., 2016).

Crop-livestock integration beyond the farm level can take several forms. According to several authors (Entz et al., 2005; Martin et al., 2016), three main types of integration projects can emerge, depending on the level of spatial, temporal, and organizational coordination among farms. The first and simplest form is a partnership between specialized crop and livestock farms (farm-to-farm), where they exchange raw materials (manure, grain, fodder, and straw). A second type of direct exchange can be organized by local groups of crop and livestock farmers negotiating land-use allocation patterns. Furthermore, a third type involves upscaling to, for instance, a regional scale where spatially separated groups of specialized livestock and crop farmers integrate through coordination by a third party (e.g., agricultural cooperative or firm). Here, the farmers involved are not necessarily communicating directly.

Organizational challenges farmers face when they initiate, implement, and sustain projects of crop-livestock integration can be obstacles to the success of entire projects, regardless of their type. This is because integration beyond the farm level always requires coordination among multiple participants and the management of trade-offs between individual and collective objectives and performances (Ryschawy et al., 2017). The time and money spent for coordination and management may be additional costs in addition to the implementation costs of on-farm integration, needing to be minimized. Due to a lack of adequate measures and framework for the analysis of organizational coordination, the critical determinants of the emergence and outcomes of integration beyond the farm level are not analyzed. As such, research has been sparse on how farmers strategically and collectively overcome these challenges. This lack of knowledge limits crop-livestock integration beyond the farm level.

In this context, our study first proposes an analytical framework to address crop-livestock integration beyond the farm level, from the perspective of Williamson's transaction costs economics (Williamson, 1985) and Ostrom's institutional analysis and development (IAD) framework (Ostrom et al., 1994; Ostrom, 2005). We use this framework for cross analyzing six projects as case studies, in which we assess the determinants of the emergence and outcomes of integration. Here, the emergence and outcomes are evaluated qualitatively as transaction costs derived from the three phases of project development: information gathering, collective decision-making, and operation and monitoring. Based on our interpretation of these six projects, we identify attributes crucial for crop-livestock integration development and durability. By so doing, we try to understand farmers' collective strategies to reducing integration transaction costs. Finally, we conclude with policy implications and recommendations for the further development of crop-livestock integration beyond the farm level.

2. Materials and methods

2.1. Analytical framework

2.1.1. Transaction cost economics to analyze crop-livestock integration beyond the farm level

Applications of the theory of transaction cost economics (Williamson, 1985) allowed us to analyze crop-livestock integration projects, to explore organizational challenges of farmers in initiating, implementing, and sustaining integration beyond the farm level. Transaction costs can be defined as the costs arising not from the production of goods, but from their transfer from one agent to another (Niehans, 1971; Mettepenningen et al., 2011). They take numerous forms (e.g., Holloway et al., 2000), and Matthews (1986) distinguished ex-ante and ex-post transaction costs respectively corresponding to the processes of achieving an agreement and continuing to coordinate its implementation (Cacho et al., 2003).

As already discussed by Asai et al. (2014a), transaction costs have a major impact on the arrangement of integration beyond the farm level. Based on the literature (e.g., Hobbs, 1997; Abdullah et al., 1998; Widmark et al., 2013), we identified three main types of transaction

Table 1
Types of transaction costs for crop-livestock integration beyond the farm level.

Transaction cost category	Examples
1) Information gathering costs	– Acquiring new knowledge of, for example, machinery, crop/animal variety, animal feeding, organic manure use, employment systems – Gathering potential partner information, such as ● the quantity and quality of products that is ready to exchange ● the willingness of farmers to change their current practices for increased coordination (e.g., changing crop rotations) ● the equipment available (e.g., tractor and trailer) to harvest, transport, and store the products being exchanged – Collecting technical-economic data for the consultation
2) Collective decision-making costs	– Planning and coordinating land-use to accommodate the needs of partner farmers or group of farmers – Consultations and adjustment of management plans – Site visits, if necessary, in the course of adjusting management plans – Negotiating the terms of an exchange: sharing costs of transport, storage, or processing of exchanged products; investment to hire workers or buy equipment; and potential duration of contracts – Drawing up the formal contract, if necessary
3) Operational and monitoring costs	– Carrying out the resource distribution through, for example, transporting plant products and manure storage – Annual update of formal contract – Monitoring to ensure partners' satisfaction (e.g., qualities of feed and manure or payment arrangements) – Conflict resolution

costs: information gathering, collective decision-making, and operational and monitoring costs (Table 1). Information gathering costs comprise the costs of acquiring knowledge of the resource and its users, and of identifying suitable trading partners. Collective decision-making costs include cost incurred by planning and coordinating resource distribution, by taking the other farmers' usage patterns into account and physically negotiating the terms of an exchange. Operational costs are the costs of actually carrying out integration and, in some cases, they may include the costs of formally drawing up a contract (Hobbs, 1997). The actual on-going exchange needs to be monitored to ensure the terms of the agreement (e.g., quality standards or payment arrangements) are carried out by the partners, resulting in accumulation of monitoring costs, including those for resolving conflicts.

Transaction costs are faced by all integration participants, but in this study, we mainly focus on: 1) farmers trying to make a farm-to-farm partnership arrangement; 2) local groups of farmers trying to integrate crop and livestock; and 3) farmers trying to contract with others through a local economic organization, such as cooperatives at the regional level. Application of transaction cost economics to analyzing crop-livestock integration projects from the viewpoint of transaction cost minimization enables us to understand the strategic choices of these farmers (e.g., farm-to-farm coordination about land-use and flows of materials) (Pingali et al., 2005; Asai et al., 2014a).

2.1.2. Modified IAD framework for analyzing crop-livestock integration beyond the farm level

Considering the transaction costs of crop-livestock integration as the unit of analysis, we propose an analytical framework that enables us to explore the organizational coordination among farmers regarding resources, land, and labor sharing. The framework encompasses three functions. First, it allows identifying and evaluating various factors that influence organizational coordination, measured by analyzing transaction costs (Table 2). Second, it deals with the temporal dynamics of crop-livestock integration, covering each phase of contracting in relation to the three types of transaction costs (Table 1), but also the entire process. Finally, it provides the analysis outcomes as strategic descriptions on how collective farmers try to minimize transaction costs under various conditions.

We have built on Ostrom's IAD framework (Ostrom et al., 1994; Ostrom, 2005) to develop our own framework (Fig. 1). We selected the IAD framework as the foundation, because: 1) it is well-suited to the analysis of collective actions across different resource systems (Ratner et al., 2013); 2) it is highly adaptable, as demonstrated by the wide range of available applications; and 3) it supports transaction costs economics. Devaux et al. (2009) adjusted the IAD to analyze collective action in market chain innovation. We proceeded similarly by slightly modifying Ostrom's framework to better match the challenges of crop-livestock integration beyond the farm level. The novelty of our framework is integrating the three phases of crop-livestock integration implementation in the Organizational Coordination Arena, particularly Ostrom's Action Arena. The Organizational Coordination Arena is influenced by four sets of variables (external environment, resources attributes, actor attributes, and arrangement attributes; Table 2), leading to different outcomes.

Based on the literature (e.g., Agrawal, 2001; Devaux et al., 2009; Mettepenningen et al., 2011; Coggan et al., 2010, 2013; Asai et al., 2014a; Moraine et al., 2016a), we identified a number of factors that are likely to influence organizational coordination and thus transaction costs in the context of crop-livestock integration (Table 2). These factors can be divided into external environment (economic/political/social factors) on one side, and internal characteristics (attributes of resources, participating actors, and arrangements between partners or among groups) on the other.

The performance of crop-livestock integration contracting can be measured by analyzing the transaction costs associated with organizational coordination (Imperial, 1999; Hardy and Koontz, 2010). The identification of factors that impact transaction costs can be assessed for 1) each phase and 2) the whole process. As indicated by the broken lines in Fig. 1, these outcomes may influence the processes that take place within the Organizational Coordination Arena. For example, successful coordination among farmers may stimulate participants to invest more time and resources into joint activities. Over time, outcomes may also influence the four groups of exogenous factors. For example, successful coordination may predispose policy makers to support future programs involving crop-livestock integration.

Table 2
Determinants of emergence and outcomes of crop-livestock integration beyond the farm level.
Sources: Agrawal (2001), Devaux et al. (2009), Mettepenningen et al. (2011), Coggan et al. (2010, 2013), Asai et al. (2014a), and Moraine et al. (2016a).

External environment (i.e., political, economic, and social contexts)
– "Trigger" for initiation of collective organization ● Policy regulations of, for instance, nutrient use, land-use changes ● Policy incentives for establishing recycling systems, crop substitution/diversification, for example ● Changes in prices of inputs and outputs ● Emergence of niche markets for local and/or organic products, for instance – Support from external agents (e.g., advisory service, research institutions, or NGOs) to stimulate crop-livestock integration and provide technical and institutional backstopping – Presence of community groups/organizations/professional networks
Attributes of resources (manure, feed, labor, farmland, etc.)
– Scarcity (supply relative to demand) and specificity (e.g., requirement for 100% organically-produced feed) – Temporal and spatial distribution – Requirements of specific equipment/machinery/knowledge for management
Attributes of participating crop-livestock integration actors
– Knowledge and experiences of agriculture in general and specific conditions – Past successful experiences of working together, which lead to social capital and trust relations – Presence of social networks with appropriate leadership and shared norms – Heterogeneity of endowments, homogeneity of identities and interests (e.g., predisposition to long-term realization of benefits)
Attributes of arrangements between partners/among groups
– Autonomy of farmers in governance rules between partners/among groups – Locally-adapted rules that are simple, easy to understand, and easy to enforce – Fairness of allocation for integration costs and benefits – Longevity of contracts with a collective vision of dealing with intra- and inter-annual variations in weather and market conditions

2.2. Case studies

The framework is applied to six case studies (Table 3) of crop-livestock integration beyond the farm level, already implemented or where implementation is ongoing. These six case studies are from four countries (Japan, France, the Netherlands, and the USA) with distinct farming systems (conventional and organic). There is a wide variety of studies (e.g., Entz et al., 2005; Regan et al., 2017) about crop-livestock integration beyond the farm level, but we selected these six based on the following two criteria. First, case studies had to match the above-cited types of crop-livestock integration beyond the farm level: 1) farm-to-farm, 2) local groups, or 3) regional integration through a third party.

Second, case studies had to have been observed and documented during the three phases of project initiation, implementation, and monitoring. We thus identify factors that increase/decrease the transaction costs of crop-livestock integration during each phase, but it may also be interesting to see, for instance, if high investments during one phase may result in lower costs in other phases or for finalized entire

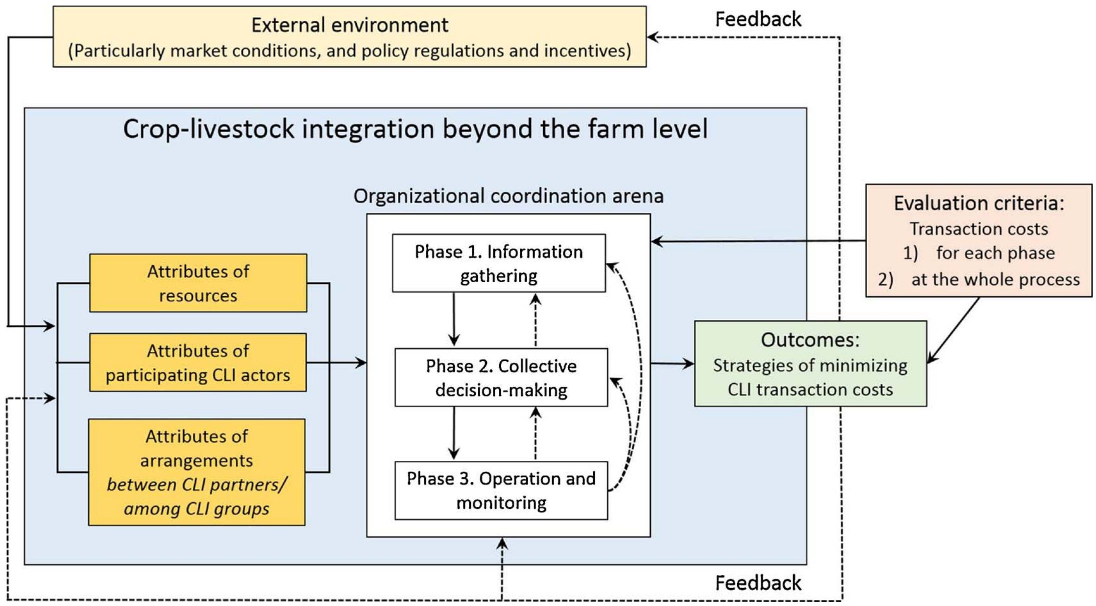

Fig. 1. Framework for analyzing crop-livestock integration (CLI) beyond the farm level.

projects. Additionally, some projects may succeed in starting, but fail in the long term. Therefore, our case study approach focused not only on successful projects but also failures, to assess influential factors. Although most of the literature on crop-livestock integration beyond the farm level describes current situations (Asai et al., 2014a,b) or possible arrangements (Moraine et al., 2016b, 2017), literature on temporal dynamics is scarce.

Based on the available literature (particularly two Japanese case studies) and the authors' participation in actual projects (e.g., a regional project from France), we selected two farm-to-farm projects from the Netherlands and the USA, two local group projects from Japan and France, and two regional projects from Japan and France. It should be stressed that, as mentioned earlier, these six case studies are not success stories in all aspects. They have developed due to favorable conditions, but they also face challenges.

2.2.1. The Netherlands: farm-to-farm crop-livestock integration between organic farmers

From 1998 to 2004, the Louis Bolk Institute executed several crop-livestock integration projects among organic farmers in the Netherlands. Organic farming covered around 2.5% of all agricultural areas in 2003, with specialized dairy and arable production dominating land use (around 70% and 23%, respectively), but with large regional differences (Prins et al., 2005). The Dutch government contributed to these projects by stimulating organic farming and facilitating legislative changes for organic feed and manure utilization. Integration typically involves informal, longer-distance business partnerships with limited communication and collective planning and searching for closer integration opportunities.

In 2001, a project started in the south-western part of the Netherlands, primarily with recently converted farmers. Among the participants were two arable farmers managing 70 and 65 ha, respectively, who came into contact with two other dairy farmers 50 and 26 km away, respectively. To fulfil part of the dairy farmers' feed demand, the arable farmers decided to produce grass-clover as roughage and not cereals for concentrate, as this seemed to fit better with their intensive arable rotations, dominated by potatoes and vegetables. Although transport costs would be high for grass-clover, it would provide soil organic matter and N-fixation, with very low labor requirements for cultivation, since all field work was done by a contractor coordinated and paid by the dairy farmers. The amount of manure exchanged depended mainly on the delivering capacity of the dairy farmers ("surplus manure"), which was below the obligatory 20% of the manure demand of arable farmers, who continued to buy organic manure on the market (De Wit et al., 2006). Prices, volumes, seed mixtures, etc. were discussed during a yearly visit ("drinking a cup of coffee"), while minor decisions (e.g., timing of delivery) were discussed by telephone. None of the agreements were written down or registered.

In 2004, the two arable farmers merged their farms, while the first dairy farmer initiated an informal cooperation with three other livestock farmers to combine their demand for feed and manure supply. All livestock farmers knew each other from several producer organizations. This informal cooperation pooled organic manure supply and demand for grass-clover from the merged arable farm, in addition to buying from and selling to other arable farms. Consequently, the original second dairy farmer had to seek a new partner, a large (over 100 ha) arable farmer 14 km away. This limited distance facilitated the use of irregular vegetable surpluses (red beet, cabbage, maize cobs, etc.) to supplement the 12 ha of grass-clover.

The intention of the informal cooperative was to seek opportunities to form regional integrated mixed farms, even considering the development of a "complementary organic arable farm" at closer distance (to reduce transportation costs). This appeared as over-ambitious, partly because the allocation and responsibility for financial risks appeared problematic and urgent, as concentrate ingredients seemed expensive to produce locally (De Wit et al., 2006). Therefore, they continued their usual habit of one-to-one informal agreements, with prices and volumes loosely coordinated amongst the three dairy farmers.

2.2.2. USA: farm-to-farm crop-livestock integration between potato and dairy farmers

Maine, like other areas in the USA, has seen a trend toward the specialization and spatial separation (over 300 km) of crop and livestock farms. In Maine, dairy farms are concentrated in the "dairy belt" in the central/south part of the state, which is more conducive to growing corn, while 90% of the potato farms are clustered in Aroostook County, to the north. Starting in the early 1990s, two pairs of potato and dairy farmers in central Maine started to integrate their cropping systems. Since these farmers are close neighbors (below 20 km) and, in one case, related, establishing trust and a long-term vision of mutually shared benefits was easy (Files and Smith, 2001). From the late 1990s to the mid-2000s, University of Maine researchers and Extension and

Table 3
Summary of the six case studies.

Country (Abbreviation)	The Netherlands (NLD)	USA (USA)	France (FRN1)	Japan (JPN 1)	Japan (JPN 2)	France (FRN2)
Location	South-west region	Maine	Tarn et Garonne	Hilly/mountain areas of Hiroshima	Nasu region	North-western France
Integration type	Farm-to-farm	Farm-to-farm	Local group	Local group	Regional	Supra-regional
Farming system	Organic	Conventional	Organic	Conventional	Conventional	Conventional
Objectives of crop-livestock integration	– Requirement for organic agriculture – Manure management	– Farm expansion – Manure management	– Self-sufficiency for organic fertilizers/feed	– Preservation of farmland – Rural development	– Feed self-sufficiency – Manure management	– Compliance with EU directive – Manure management
Resources exchanged	Manure, fodder	Manure, land sharing, equipment, and labor	Manure, alfalfa hay, grain, mixed crops	Forage rice, composted manure	Forage rice, composted manure	Composted manure
Actors involved	Organic dairy farmers, organic crop farmers, advisors, research institute	Dairy farmers, potato farmers, university, advisors	Organic livestock farmers, organic crop farmers, research institute	Livestock farmers, rice farmers association, advisors	Dairy farmers cooperative, rice farmers, advisors, contractor	Pig farmers, private company
Contract formality	Semi-formal ("verbal contract" updated yearly, sometimes formalized by email/paper with few lines of agreed transactions)	Informal (a formal contract was developed but not used)	Informal	Semi-formal	Formal contract in relation to subsidy application	Formal signed contract
Duration of project (at the time of the research)	On average > 9 years	From minimum 2 years to > 10 years	2 years (first year with 24 farmers and second with 6 motivated farmers)	> 5 years	> 5 years	> 5 years
Reference(s)	Nauta et al. (1999), De Wit et al. (2006), De Wit and de Adelhart Toorop (2017)	Files and Smith (2001), Hoshide et al. (2006)	Ryschawy et al. (2017), Moraine et al. (2017)	Tsunekawa (2007), Tsunekawa and Horie (2009)	Tsunekawa (2010, 2013, 2015), Tsunekawa and Miyaji (2010)	Moraine (2016)

farmers began quantifying and promoting the economic, agronomic, and community benefits of such "coupled" crop-livestock integration. Due to these efforts, eight other potato and dairy farmers started integration.

The key driver to short-run "coupled" integration benefits is the negative profitability of low-value food or feed grains grown in rotation with potatoes. By growing more profitable dairy forage crops, coupled farmers can mutually share benefits. If the traditional potato rotation crops of small grains and maize grain were more profitable, this short-term integration benefit would not exist. Short-run coupled relationships typically start with land swapping and, in the long run, evolve into more complex exchanges, involving feed and even shared inputs such as equipment and work crews. After a decade, the economic benefits of crop-livestock integration include a 5% higher potato yield, especially in dry years due to manure amendment in the rotation year. Additionally, fertilizer and pesticide use decrease due to the expanded land available for crop rotation. Expansion and increasing yields boost revenues, and when combined with reduced input costs, profitability increases (Hoshide et al., 2006).

While the spatial proximity of farmers that are integrating their cropping systems is necessary, it is not sufficient, since both producers have to get along. A specialized potato and dairy farmer in southern Aroostook are next-door neighbors, yet only briefly experimented with integration in the mid-2000s, ultimately having to terminate it, since they could not agree on pH management. Conversely, over the same period, another specialized dairy and potato producer pair in southern Aroostook got along, but the excessive distance (below 20 km) between their fields led to the end of their integration experiment. Research and farmer investigation into dairy farm relocation to Aroostook County in 2006 to facilitate more coupled integrations has proved challenging due to the Great Recession and weak macroeconomic recovery, increased cost of milk transport, and resistance on the part of Aroostook potato farmers to use livestock manure (Hoshide and Smith, 2007).

Although this produced a formal contract for potential integrators, it has remained unused due to a lack of new farmers interested in integration. Historically, long-term integration between partnering farmers has been based on informal verbal agreements (no formal contracts). These informal arrangements rely on the faith that both parties benefit in the long run and de-emphasize which party may be benefiting more in the short run. Despite these initial successes, participation has not expanded beyond these initial dozen farms due to exhausting the limited group of potato and dairy farmers close enough both spatially and collaboratively. For the original two pairs of coupled producers, other challenges to long-term integration have arisen over the past decade. One of the original integrators has downsized its farm from potato to mixed vegetables, becoming less integrated with the dairy farm. Another original integrator reduced integration to bio-digest dairy manure for energy. Unlike integration, on one farm with both crops and livestock, coupled crop-livestock integration coordinated between two or more farms can strongly depend on the operational decisions of each coupler and can change even after several years of a stable working relationship.

2.2.3. France 1: Local group cooperation among organic crop and livestock farmers

In a region of south-western France characterized by clay-limestone hills, where soil depth varies highly among fields, there is coexistence of crop and grasslands and, consequently, highly diversified agricultural landscapes (Moraine et al., 2016b). Farms are limited in size, impeding on-farm diversification (crop-livestock integration at farm level) in most cases. All farmers follow organic production standards. Despite the high added value of agricultural products through direct market sales, organic fertilizers and concentrated feeds are expensive enough to become inaccessible for crop and livestock farmers.

The association of organic farmers initiated a reflection on self-sufficiency over inputs (mainly fertilizers and feed) at the local level. At that time, the advisor of the association met a PhD student from INRA, developing participatory methods supporting crop-livestock integration beyond the farm level, resulting in a collaborative project. A first study involved 24 organic farmers interested in crop-manure exchanges in the region (Moraine et al., 2017). Farm surveys were conducted to understand their motivations and farming systems. Integration scenarios were then developed and discussed with the farmers. In the end, farmers proved unwilling to start implementing these exchanges. Since livestock, crop, and combined areas were segregated, farmers felt the distance between farms as an overwhelming constraint.

In the meantime, the French ministry of agriculture launched the agro-ecological plan, which promotes the development of agroecology in agriculture, that is, agricultural systems being more self-sufficient by relying on ecosystem services, and more efficiently using inputs, while minimizing negative impacts on productivity. A call for projects related to this plan was initiated in 2013 to support bottom-up initiatives favoring agroecology development. The association of organic farmers responded to this call and obtained funding for an advisor to support them in the implementation of small-scale crop-livestock integration among farms (Ryschawy et al., 2017).

To address the constraints related to distance between farms, the advisor of the association and INRA researchers agreed to focus on a small group of six neighboring organic farmers willing to explore and implement exchanges among farms (Ryschawy et al., 2017). Four of them focus on dairy production, with cows, goats or ewes. Their feeding system is mainly based on owned grasslands and purchase of concentrated feeds. Three are diversified cash crops farmers, relying on purchased organic fertilizer and having contracts for certain crops (e.g., soya). The six farmers involved were interested in developing crop-manure exchanges to achieve self-sufficiency for fertilizers (crop farmers) and for animal feed (livestock farmers) at the group level. They also aimed to share skills and knowledge through theses exchanges.

Again, individual farm surveys were conducted and then followed by participatory design and evaluation of integration scenarios (Ryschawy et al., 2017). Three collective meetings were needed to focus and refine the scenarios. At the end, farmers felt satisfied by the scenarios and were collectively empowered to begin implementation. They collectively agreed on the crop rotations needed to produce the amounts of grain and fodder (mainly maize and alfalfa) to be sold by crop to livestock farmers. An additional meeting was organized before sowing winter crops, to refine the scenarios according to the climate conditions of the year and establish a price index governing the exchanges.

At this stage, INRA researchers quit the process, leaving the responsibility to support implementation to the advisor. Due to financial issues in the organic farmers association, the advisor's missions changed substantially, limiting day-to-day coordination among farmers. One livestock farmer finally forgot to buy maize from a crop farmer (buying instead from the local cooperative), which created conflict among farmers. The project is currently on hiatus, but the farmers' association obtained funding for re-investing into collective decision-making and implementation based on revised collective rules.

2.2.4. Japan 1: Local group cooperation among rice and cattle farmers

Rice is the most widely produced crop in Japan, including in hilly and mountainous areas. Since the human consumption of rice has been decreasing, production of forage rice as whole-crop silage (WCS) has been proposed as alternative utilization. This also supports the political goal of improving the country's low food self-sufficiency by increasing the domestic production of feed for locally raised animals, since Japan is a massive importer of animal feed. The rice-crop diversion subsidy under production adjustment programs encourages farmers to cultivate forage rice, resulting in a large expansion of production area for rice WCS (Tsunekawa, 2010).

Two projects of local crop-livestock integration were found in the hilly and mountainous areas of Hiroshima (western Japan) (Tsunekawa, 2007; Tsunekawa and Horie, 2009). In these areas, hill slopes prevent farmers from exploiting economies of scale and, thus, farm size is limited. Theses areas' major socio-economic challenges were farmers' aging and migration, resulting in the abandonment of paddy fields and destruction of local communities. Farm abandonment has particularly been seen as a critical issue, as rice paddy fields have many beneficial functions such as ground water retention, air temperature control, and flooding prevention (Tsunekawa and Horie, 2009).

The first project was initiated by one of the dairy farmers in the community, who made the first field trial of forage rice under technical support from advisors (Tsunekawa, 2007). In the meantime, a group of 18 rice farmers agreed to aggregate their small fields to produce forage rice collectively, primarily for farmland preservation in the community. The dairy farmer was also a member of this collective management and, therefore, already knew whom to contact about cropping changes. Later on, the farmer became a leader, coordinating communal integration. In 2001, the leader together with another dairy farmer and the three rice farmers started a cooperative to buy a special machine to cultivate WCS, which is now owned by the cooperative.

As of 2010, a total of 12 ha of paddy fields, coming from 7 ha from collective farmland among a group of small rice farmers and 5 ha from three individual rice farmers, was converted to produce forage rice for two dairy farmers in the same community. Manure from the dairy farmers is first composted and then applied to the paddy fields, while the forage produced is partly sold to a beef producer outside of the community. As integration was mainly organized between these five specialist farmers, decision making flexibility is high (Tsunekawa, 2007).

Another project in a second community in Hiroshima involved two rice farmer associations, who started growing forage rice in 2002 on a total of 11 ha of their paddy fields (Tsunekawa, 2007). They sell WCS to four neighboring dairy farmers. These two associations are similar to the collective group in the first example, but they consist of more participants (55 and 88 member farmers, respectively). One of the associations initiated the crop-livestock integration with an advisory service's technical support, and now takes economic responsibility for producing, selling, and delivering WCS to dairy farmers.

The association also receives manure from dairy farmers and applies it once composted to the paddy fields. The costs of this manure application may be higher than the benefits, but the association keeps this agreement to maintain stable partnerships with the dairy farmers. The first year's transaction resulted in a bad reputation among dairy farmers due to low forage quality, with some dairy farmers even terminating their contracts. The association made their best efforts to improve WCS quality to re-build trust with dairy farmers (Tsunekawa, 2007). With the exception of sustaining rice forage quality, the association has a low willingness to increase yields and, thus, make more profits due to the production adjustment program. However, most participants are satisfied with the contract because forage rice was easy to adopt due to their past experiences of farming rice and it was well-subsidized.

2.2.5. Japan 2: Regional scale crop-livestock integration

The Nasu region, located about 180 km from Tokyo, consists of three municipalities, covering the northern border of Kanto-plain and the Nasu highlands. Nearly 90% of the farmland in southern Nasu is used for rice paddy fields, whereas intensive livestock production is a major economic activity in the entire region (Tsunekawa and Miyaji, 2010). Dairy farmers are concentrated in central and northern Nasu and are major milk suppliers to the Tokyo metropolitan area. Since farm types are location-specific within the region, there were no contacts between livestock farmers and crop farmers.

Prior to crop-livestock integration establishment, livestock farm size increased, resulting in: 1) declining self-sufficiency of animal feed as cattle per farm increased and 2) a greater need for managing excess manure. Under these circumstances, the regional scale exchange between forage rice and composted manure has been adopted (Tsunekawa and Miyaji, 2010).

The establishment of a contractor company was triggered by a study group of dairy farmers using the same feed center built by local feed company in 1999 (Tsunekawa, 2010). The study group participants innovatively improved animal feed intake and increased self-sufficiency, given the growing concerns over resource recycling and the environmental impacts of farming. This initiated regional level crop-livestock integration. In 2007, with financial and technical support from the feed company and advisory services, the contractor company was launched to coordinate WCS production and facilitate exchanges between dairy and forage rice farmers.

Thirteen initial investors were responsible for 78% of the contractor company's investments, including six livestock farmers from the study group, two crop farmers, and one mixed farmer (Tsunekawa, 2013). The idea was to connect livestock and crop farmers at the regional scale, so it was essential that farmers from both livestock and crop sectors joined company committees. The establishment of the contractor company was separate from the community-based networks, emphasizing functionality and unity of purpose. The representative of the company was selected from the livestock farmers.

The main tasks of the contractor company are to produce WCS on the fields of about 35 contracted rice producers and sell the forage to about 30 dairy farmers (Tsunekawa, 2015). In 2013, 60 ha of paddy fields across three municipalities were under contract for forage rice production. Since long sustainable partnerships is one of the goals of the contractor's committee, they offer a special contract to forage rice producers to buy their forage at a fixed price, so forage producers are always assured that they can use forage rice production as a stable income source. Since 2010, the contractor also spread composted manure on the fields of some of the contracted forage producers. The manure application cost has been subsided by the government for those who produce forage rice as WCS.

To implement this contractor-based crop-livestock integration, certain economies of scale are needed to compensate for investment costs (Tsunekawa and Miyaji, 2010). For instance, in 2009, the company adopted a new harvesting machine to increase work efficiency. Prior to adoption, field trials and feasibility analysis, under technical advice from the research institute, had been conducted and discussed among committee members. Since then, the contractor has been more active in finding new WCS buyers. Attracting more buyers is feasible, since the price of imported feeds is uncertain, locally produced forage is preferred due to food safety concerns, and WCS quality is guaranteed among current users. However, the paddy fields under contract are scattered throughout the region, increasing harvesting and transportation costs for the contractor.

2.2.6. France 2: Supra-regional scale crop-livestock integration

Terrial is a private company belonging to the large agrofood cluster APRIL. In the 1990s, some confined dairy, pig, and poultry farms faced problems complying with EU standards for manure application on fields (EU Nitrate Directive from the 1990s), caused by high animal densities. Farmers did not want to reduce herd size and could not identify additional land for spreading manure. Therefore, manure had to be exported from these farms. Terrial was built for this purpose in 1996, and organizes the production, processing, transport, and commercialization of composted manure from intensive livestock farms, selling to a diversity of farms in cropping areas. Farmers pay for this service to maintain their industrial efficiency, while complying with environmental standards.

The manure collection area covers three French regions in western France: Brittany, Normandy, and Pays de Loire (Moraine, 2016). Composted manure is distributed over large areas specialized in crop or vine production: cereal plains in central and south-western France and Bordeaux vineyards. It is sold as organic fertilizer to local cooperatives by the APRIL group. Some products are even organically certified.

The supply chain is organized as follows (Moraine, 2016). First, animal manure is composted either on farm (for around 100 farmers producing around 400 metric tons of compost per year), or on industrial composting platforms (two platforms have been built and are managed by Terrial, each producing 20,000 metric tons of compost annually). The total amount of compost produced by Terrial is 100,000 metric tons/year. It is then processed by granulation at three sites using renewable energy, notably biomass boilers fed by sunflower processing waste from APRIL's animal feed factories. Transport using large trucks is organized by Terrial.

To sell these manure-based products, pricing has to be competitive with synthetic fertilizers. Processing, storage, and transport costs are added to the final price to determine whether the livestock farmer will earn something from the manure or have to pay for removal. Generally, if the manure is composted on farm, the livestock farmer will earn some money. However, if manure is collected, raw farmers pay a small amount per metric ton to cover composting costs.

The organization and coordination of manure transfers by Terrial was made possible by large investments in composting platforms and granulation factories (Moraine, 2016). Terrial has around 15 workers: drivers, workers on composting platforms and in granulation factories, commercial agents for selling products, and research/development elaborating and monitoring the organic fertilizer production process. Cost-benefits analysis and a market survey determined the development of Terrial, ensuring its economic viability. The connection with livestock farmers and reliability of the APRIL group have led to successful supply chain development.

In the future, Terrial would like to supply animal feed factories with cereals and other products coming from farms that buy Terrial's organic fertilizer. This could develop a circular economy at the supra-regional level (distances from 100 to 500 km).

3. Results and discussion

3.1. Summary of factors crucial for crop-livestock integration

Table 4 synthesizes the major factors identified through the observation and documentation of each case study. Various drivers of crop-livestock integration beyond the farm level (external environment) were identified. Those include regulations on manure application and input use in organic farming, financial incentives, and presence of coordinator (third party). Technical support by external agents was commonly found in all case studies. The impacts of internal characteristics (attributes of resources, participating actors, and arrangements between partners or among groups) on the transaction costs of 1) information gathering, 2) collective decision-making, and 3) operation and monitoring are respectively described in the following subsections.

3.2. Determinants of information gathering for integration implementation costs

Active social networks, such as farmer associations, play a key role in lowering the costs of identifying suitable integration partners in the JPN1, FRN1, NLD, and USA case studies. Uncertainty of information about what other farmers are doing is a critical barrier to starting crop-livestock integration collectively, which increases information gathering costs. Required information includes the quantity and quality of materials to exchange, farmers' willingness to change their current practices towards increased coordination (e.g., changing crop rotations, introducing new crops), and the equipment available (e.g., tractor, trailer) to harvest, store, and transport the products being exchanged. On the other hand, as shown by JPN2 and FRN2, being highly connected with other farmers through social networks may not be required when an economic organization already developed a network of integrating farmers. Therefore, famers can lower information gathering costs by connecting to this organization, such as the case of the Group

Table 4
Summary of attributes crucial for crop-livestock integration among the six case studies.

Crop-livestock integration factors	Attributes[a]	NLD	USA	FRN1	JPN1	JPN2	FRN2
External environment	Regulation on nitrate/nutrient management	↑	↑			↑	↑
	Subsidy for forage rice production				↓	↓	
	Financial support for project development			↓			
	Organic 100% use policy	↑		↑			
	Input price change[b]						↑/↓
	Third-party organization's coordination					↓	↓
	External agent's technical support	↓	↓	↓	↓	↓	↓
Attributes of resources	Specificity (organically produced manure and feed use)	↑		↑			
	Scarcity (available land for spreading manure)	↑					↑
	Spatial proximity of partner farms	↓	↓	↓	↓		
	Large coverage area of integration					↑	↑
	Special harvesting machine for whole crop silage, for example				↑	↑	
Attributes of actors	Strong trust relations		↓				
	Active social networks	↓	↓	↓	↓		
	Large number of participants					↑	↑
	Presence of appropriate leadership				↓		↓
	Shared goals between partners/among groups	↓	↓	↓	↓	↓	↓
Attributes of arrangements	Establishment of clear rules through face-to-face interactions	↓	↓	↓	↓		
	Informal trust agreement		↓	↓			
	Formal contract with signed agreement[c]					↑/↓	↑/↓
	Annual partners' meeting (typically no signed agreement)	↓					
	Special contract to buy forage at a fixed price					↓	
	High autonomy of farmers in governance among groups[d]			↑/↓	↑/↓		

[a] ↑ indicates the attributes increase transaction costs in general, while ↓ indicates the attributes reduce transaction costs. ↑/↓ means both cases as explained below.
[b] A decrease in input price (i.e., synthetic fertilizer) can make manure less competitive and result in high costs, such as, finding potential manure receivers, while an increase can make it more interesting to use for crop farmers and reduces costs.
[c] A formal contract is costly to develop, but it contributes to low monitoring costs once signed.
[d] Both increasing and reducing transaction costs are possible as, for instance, FRN1 failed once farmers were allowed too much autonomy.

Environmental Farm Planning in Saskatchewan, Canada, where information gathering costs (e.g., gathering information and identifying funding sources) were reduced because of assistance received from local NGOs/NPOs (OECD, 2013).

When resources are not scarce nor widely scattered in space, there is no need for farmers to invest extra time and money (i.e., low information gathering costs) to look for integration partners matching their needs, as illustrated by the JPN1, JPN2, and USA case studies. Here farms engage in "external coordination" with other farms. However, high transaction costs, including those for information collection necessitate the "internal coordination" of crop-livestock integration through third-party organizations (Barkema, 1993). The costs of collecting information increase as the degree of resource specificity increases (see organic farmers, NLD, and FRN1). European regulations require 100% organic feed for organic dairy cattle and rules are tightening for manure application from conventional livestock production to organic cropping systems. Where there is no alternative to use specific resources (e.g., organically-produced), finding suitable trading partners may increase information gathering costs, as partly discussed in relation to the Danish organic crop production sector (Oelofse et al., 2013; Asai and Langer, 2014). These costs may also increase when usual partners encounter problems, such as shortage of harvests due to drought. Other examples of information gathering costs increasing along with resource scarcity are FRN2 and NLD: livestock farmers faced the challenge of complying with environmental regulations, making "land for spreading manure" a scarce resource. In NLD, livestock farmers could find partners, establish arrangements and reorganize practices. In FRN2, livestock farmers were unable to overcome the information gathering cost (i.e., finding "spreading partners"), and thus they had to transfer these costs on to an organization with the capacity to develop a network of crop farmers willing to pay for manure. Therefore, the costs of gathering information and actual operation should be high in areas with a high density of intensive livestock production units, as livestock farmers face high competition in gaining access to crop farmer fields, as shown by Asai et al. (2014a).

Besides resource scarcity and specificity, requirements for specific equipment, machinery, knowledge, or conditions for starting crop-livestock integration (Russelle et al., 2007; Bell and Moore, 2012) may be critical factors that increase or decrease information gathering costs. For instance, in JPN1 and JPN2, rice farmers were ready to adopt forage rice production as they were experts of rice farming, but they had to dedicate some time to get trained in using the special harvesting machine. By contrast, in FRN2, the absence of farmers' specific skills enabled the fast development of the economic organization facilitating crop-livestock integration.

3.3. Determinants of collective decision-making for integration implementation costs

As observed in all case studies, being supported by professional groups, hiring consultants, and/or collaborating with research institutes can be effective strategies to lower costs of, for instance, planning land-use by adjusting to other farmers' needs, coordinating temporal and spatial distribution of resources, and choosing the best agricultural practices by considering partners' needs. Previous studies (Breetz et al., 2005; Asai et al., 2014a) found that past successful experiences of working together reduced the costs of collective decision-making, as they promote the development of social capital and trust. However, our observations on some of the case studies (JPN1, JPN2, NLD, and USA) reveal that past working experiences may not be necessary, as long as adequate investments are made into researching the appropriate information about potential partners. By contrast, FRN2 minimized transaction costs through internal coordination by a private company with sufficient economies of scale, but the drawback of this strategy is low decision autonomy for farmers.

Planning with an experienced and well-established partner is another strategy to minimize uncertainty (Williamson, 2000), and can lower collective decision-making costs. However, selecting and working only with knowledgeable and stable partners is not always feasible, as seen in FRN1 and NLD. There, several French farmers were still in the development stage, which partly explains why crop-livestock integration took more time to emerge than originally planned. For NLD, it is the structural development of organic farms that made integration challenging. These findings suggest more integration stability and persistency require long-term interactions. Shared willingness to achieve long-term benefits, such as through ecosystem services like soil fertility or through more stable prices, should be essential, as previously suggested (Andersson et al., 2005; Martin et al., 2016). The costs of achieving an agreement favoring long-term benefits can be reduced at the information gathering stage by ensuring that these benefits are acknowledged and targeted by all farmers (see FRN1).

As commonly seen in the case studies organized through face-to face-interactions between partners or among group members (NLD, USA, FRN1, and JPN1), the establishment of clear rules (prices, amount, and timings of deliveries, etc.) with fair allocation of costs and benefits seems to be essential for lowering the costs of negotiation among partners/group members. These rules are not necessarily formal, as long as there are shared norms, and ideally rule-making should proceed and be coordinated by appropriate leadership, as seen in JPN1, or in a different way (FRN2), where the "leader" has a dominant position towards farmers. This could be further enhanced if farmers perceive themselves as a group acting or responding jointly to a shared problem or resource, as pointed out by Mills et al. (2011) for landscape-scale resource management within agri-environment schemes in Wales.

3.4. Determinants of integration operation and monitoring costs

In most case studies, to avoid contract nonfulfillment or opportunistic behavior, making a formal contract with a statement of long-term trading is safer than an informal agreement. The disadvantage of informal agreements may be a lack of clarity regarding the procedures found in a contract for actions (e.g., which resources are to be exchanged, how much, and when) and the related outcomes. In FRN1, the project was compromised due to disrespect for informal agreements. However, exhaustive contracts are costly to develop, incurring costs from information collection requirements and from time and other resources required during contract negotiation and completion (Coggan et al., 2013). These costs can be covered by stakeholders at the appropriate critical size, like in FRN2. Farmers may be also unwilling to face new constraints, such as loss of autonomy in individual decision-making and dependence on other farmers for decision-making and action (Moraine et al., 2014).

By contrast, some partnerships between US dairy and potato farmers are long-lasting without any formal contracts. Files and Smith (2001) emphasized that basic trust between individuals in Maine, USA was a key requirement for lengthy partnerships. Trust ensures that an exchange partner will not act in self-interest at another's expense, and provides confidence in an exchange partner's reliability and integrity (Morgan and Hunt, 1994), resulting in low costs for decision-making and monitoring. Moreover, studies on other types of farmer collaborations, such as joint farm ventures (Ingram and Kirwan, 2011), environmental management (Macfarlane, 1998; Mills et al., 2011), and machinery sharing (Emery and Franks, 2012), showed that only when an informal relationship had already been established there was a commitment to formalize a long-term partnership, as seen in the Maine case study.

The success of crop-livestock integration beyond the farm level depends on the spatial proximity of farms, as shown in several case studies (JPN1, FRN1, NLD, and USA). Araji et al. (2001) highlight the distance travelled during hauling and spreading is the most important variable in terms of the cost of using manure as a crop fertilizer. Therefore, the operational costs, particularly those accrued from the physical distribution of resources, would be low when resources are available in close spatial proximity and when there is no need for specific equipment. Resource specificity can be a critical factor as well, as crop-livestock integration between organic dairy and crop farms may be costly in areas where organic farms are scattered. Although our case studies did not empirically compare between organic and conventional systems, a study from Denmark shows that organic crop farmers need to transport longer than conventional to receive manure from organic dairy farms (Asai and Langer, 2014).

However, as illustrated in JPN2 and FRN2, the issue of spatial proximity can be overcome where the costs for participating actors to make integration happen are covered through extending the scale of integration in terms of coverage area and number of participants, to exploit economies of scale. In contrast to the USA case study, where crop-livestock integration happens when farmers are close enough (maximum 20 km), the JPN2 and FRN2 case studies show that other entities aside from farmers could cover the added costs of transporting resources regionally well beyond 20 km. This type of regional-level crop-livestock integration is relevant between areas with high specialization. Long distance to partners may prevent good communication and, thus, efficient access to proper information, increasing operation and monitoring costs. Therefore, appropriate coordination by a third party (e.g., a private company in FRN2 and contractor in JPN2) is essential. Furthermore, the operation and monitoring costs of regional crop-livestock integration can decrease due to an efficient scale of coordination, as long as the information and decision-making processes are fairly evaluated.

Theory suggests that, when transactions between the same partners/group members are recurring, transaction costs across all transactions can be reduced by designing a suitable contract (Williamson, 1981; Coggan et al., 2013), which can reduce information collection and search costs for each individual transaction (Rorstad et al., 2007; Mettepenningen et al., 2009). A key concern for long-lasting integration is how to deal with intra- and inter-annual variations in weather and market conditions, which can compromise the amounts of resources exchanged. For instance, FRN2 crop farmers' willingness to accept manure partly depends on the fluctuating prices of mineral fertilizers: they are more open to receive manure or use cover crops when the price of mineral fertilizers is high (Schipanski et al., 2014). Livestock farmers are obliged to dispose of manure to comply with environmental regulations, paying a fee to keep the price of manure competitive against that of mineral fertilizers. Therefore, long-lasting coordination between farmers requires that they work together with variation rather than against it (Lyon et al., 2011) within a framework of contracts.

4. Conclusions and policy implications

Despite the recognized benefits of agriculture sustainability, crop-livestock integration beyond the farm level has been poorly documented so far, which limits its implementation. We developed the IAD framework, which enabled us to assess critical determinants of the emergence and outcomes of integration, and therefore helped us better understand farmers' collective strategies to reduce integration transaction costs. The application of the framework to six case studies demonstrated it can be applied to various projects, implemented at multiple organizational levels (farm-to-farm, local groups, and regional levels) over distinct farming systems (conventional and organic). It highlights that social and organizational resources mobilized for integration depend on the agricultural context, stakeholders involved and prior relationships, culture, etc. Therefore, no recipe or unique strategy could be specified, but public policies and institutions could evolve to reinforce attributes crucial for crop-livestock integration development and durability. In what follows, we conclude with policy implications and recommendations by highlighting the importance of financial and technical support, and strengthening social networks for further development of crop-livestock integration beyond the farm level.

Specific policies should be developed to encourage the introduction and maintenance of integration beyond the farm level. They involve various forms of financial and technical support, targeted to different integration types, participants, and project stages. For example, crop-livestock integration at the farm-to-farm or local levels involves new transaction costs, especially in the beginning, preventing further development. Therefore, initial financial support from the government can be useful in promoting crop-livestock integration, because both the projects/organizations being developed and the financial basis of farmers (e.g., in terms of investment and hiring consultancy) are weak. For integration at local group and regional levels, initial transaction costs can be covered by intermediary actors such as farm advisors and firms. However, from a public policy viewpoint, these costs have to be balanced with the expected environmental benefits.

Knowledge development and its implementation through technical advising is also crucial, in addition to financial support from governments (Garrett et al., 2017). One of challenges of crop-livestock integration beyond the farm level is that farmers face more complexity (Maletič et al., 2014) from doing things better (i.e., innovation through better use of resources) versus doing things differently (i.e., innovation through exploration of new resources). To receive economic and environmental benefits, locally-adapted crop-livestock integration systems need to be well-designed via collaboration with scientists and advisory services. The simulation models and participatory methods developed and implemented by these actors can support iterative design and evaluation of scenarios to characterize trade-offs among integration options and identify consensual solutions for farmers (Martin et al., 2016). The funding processes that develop social interactions can thus stimulate partnerships, particularly between farm associations and scientists at research institutes/universities to explore crop-livestock integration innovations and exchange knowledge, creating mutual benefits.

Strong social networks can reduce the transaction costs associated with organizational coordination, as shown in all case studies. They help farmers identify suitable partners, develop plans collectively, and leverage available resources. Therefore, it is essential to strengthen social networks and involve the wider community, including the private sector. In France, for example, the Agroecological Plan has set up farmer groups, such as the Ecological and Economic Interest Group, to develop projects related to agroecology. These pioneering groups encourage collaboration with researchers, supply chains, and local stakeholders. Moreover, financial incentives from the government support these diverse groups of farmers.

Crop-livestock integration beyond the farm level often requires new networks, as current networks often include either specialized arable or specialized livestock farmers, particularly if regional specialization exists. Stimulating new networks may require approaching local leaders or “reference farmers,” who have some influence on other farmers’ behaviors, since trust is essential to strengthening social networks. Policies should thus incorporate links with existing networks and institutional arrangements in designing crop-livestock integration beyond the farm level. Furthermore, governments can motivate potential actors by distributing information on successful cases and holding outreach events to identify the environmental and economic benefits of integration.

A formal legal framework for establishing crop-livestock integration can be useful, since it can increase the credibility and stability of partnerships. For instance, the creation of a formal contract, in which participants only need to fill in the lines when they have agreed upon such arrangements, may resolve conflicts. In Denmark, for instance, farmers are obliged to submit annual fertilizer accounts to the authorities, reporting on produced, applied, received, and provided fertilizer and manure (Asai et al., 2014b). If a livestock farmer has provided manure to another farmer, it requires submission of a formal letter with the manure receiver’s signature. This type of obligation helps ensure the partnership is not violated and that the terms of the agreement are carried out by the partners, resulting in lower monitoring costs and longer-lasting partnerships.

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