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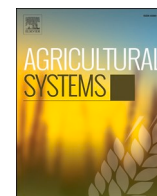
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Work in agriculture: A blind spot in reducing pesticide use on dairy farms?

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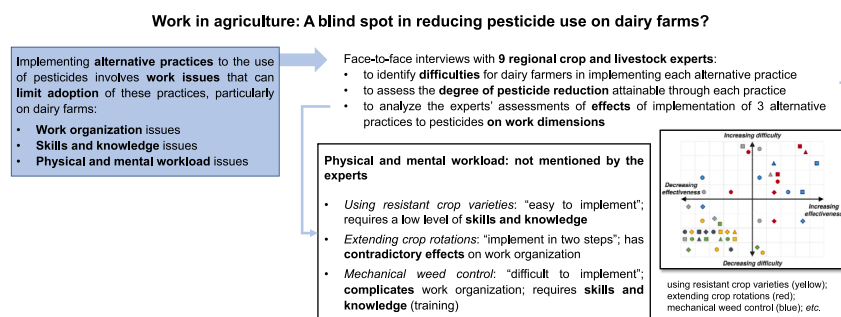
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HIGHLIGHTS

- Agricultural work plays a critical role in reducing pesticide use on dairy farms.
- Nine experts discussed the impact of work dimensions on reducing pesticide use.
- Physical and mental workload was never mentioned as a limiting factor.
- Work organization and skills and knowledge were the main difficulties mentioned.
- Alternative practices to reduce pesticide use can be difficult to implement on dairy farms.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Implementing alternative practices to the use of pesticides involves work issues that can limit adoption of these practices, particularly on dairy farms. Depending on how practices change, work organization may completely change, additional skills and knowledge may be required, and system complexity may increase, inducing a higher mental workload. This can result in an excessive total workload for already overburdened farmers.

OBJECTIVE: The present study examines whether work limits the implementation of alternative practices to reduce pesticide use on dairy farms, depending on the amount of change the practices require. Three work dimensions were considered: work organization, skills and knowledge, and physical and mental workload.

METHODS: We used nine semi-structured interviews with crop and livestock experts in Brittany (France's leading region for dairy production) to classify multiple categories of practices by their degree of difficulty and the type of work dimension involved, with a specific focus on three practices: using resistant crop varieties, mechanical weed control and extending crop rotations.

RESULTS AND CONCLUSIONS: First, experts emphasized certain alternative practices over others depending on the institution to which they belonged. Second, the need to balance the feeding system and an increase in herd size, which is not compatible with all alternative practices, were barriers specific to dairy farms. Third, all three practices we focused on were skill- and knowledge-intensive, but in different ways. Using resistant crop varieties requires access to the right information, while mechanical weed control raises issues of training, investment or outsourcing. Finally, extending crop rotations, considered as a redesign of the production system, requires obtaining the resources, time and autonomy to think about new rotations.

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SIGNIFICANCE: This study shows that, in addition to work organization, other work dimensions are crucial for reducing pesticide use on dairy farms.

1. Introduction

During the past 50 years, the use of pesticides for crop management has become widespread in France (Chauvel et al., 2012; Urruty et al., 2016; Hossard et al., 2017). However, due to their impacts on the environment and human health (e.g., Jokanović, 2018; Rigal et al., 2023), the objective of reducing their use was officially set in France in 2008, through the ÉcoPhyto plan, and continues in the plan's current

version, ÉcoPhyto II+ (Ministère de la Transition écologique et solidaire, 2018). At the European Union (EU) level, the Green Deal (2019) also set the goal of reducing pesticide use by 50 % by 2030, through the Farm to Fork strategy.

Scientific and technical literature has long reported existing alternative practices to reduce pesticide use (e.g., Way and van Emden, 2000; Gaba et al., 2015; Pannacci et al., 2017; Syed Ab Rahman et al., 2018; MacLaren et al., 2020; Cisternas et al., 2020; Wuest et al., 2021;

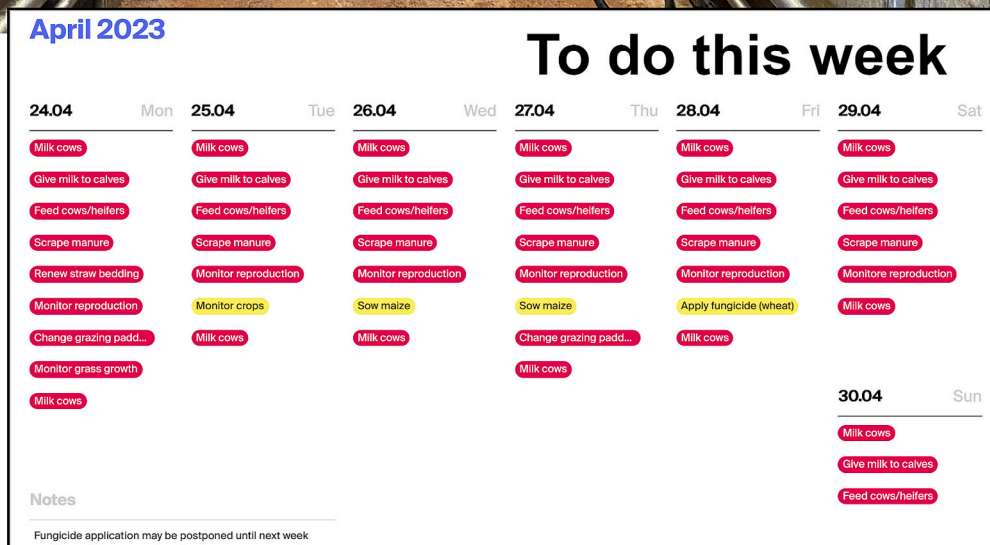
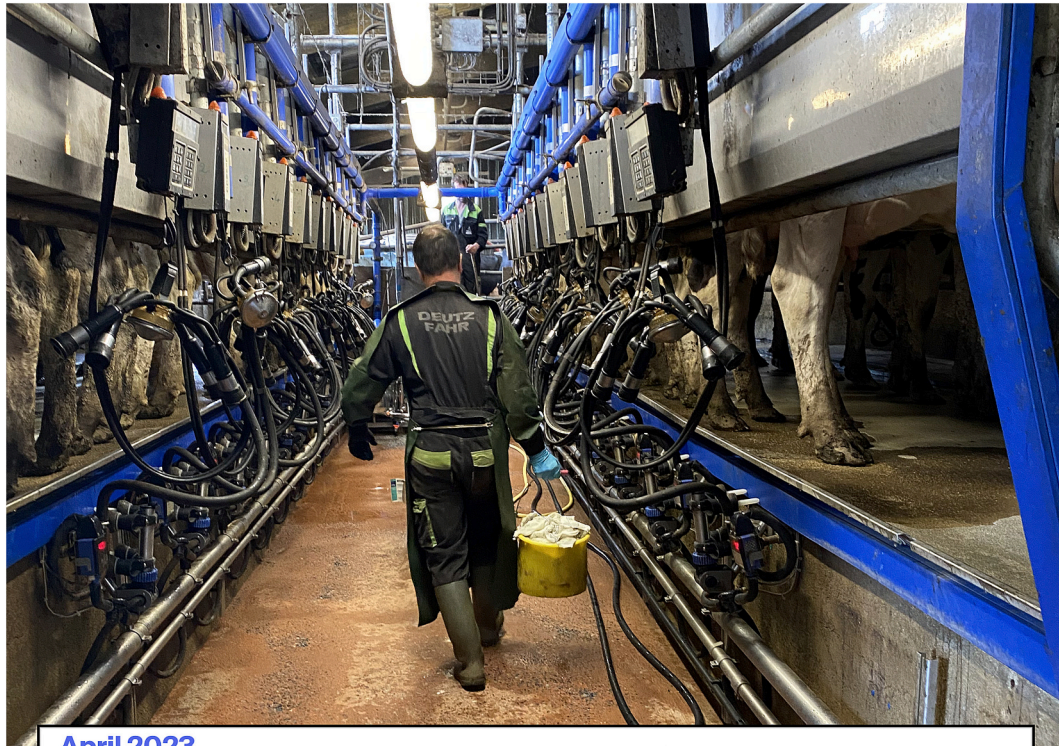


Fig. 1. Work on a dairy farm prioritizes the livestock system, which requires many routine tasks that cannot be postponed. Thus, the cropping system comes second in the work organization, which can considerably hinder implementation of alternative practices to pesticides. The upper part of this figure shows a farmer milking and caring for his cows, a twice-daily activity that can take several hours depending on the size of the herd (Photograph: Marie Le Luel). The lower part of this figure shows a fictional but realistic example of a weekly schedule with the tasks dedicated to the livestock or cropping systems (red and yellow, respectively). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Gardarin et al., 2022): implementing precision agriculture, changing sowing dates, using resistant crop varieties and crop-variety mixtures, mechanical weed control, biocontrol, using intercropped service crops, extending crop rotations and diversifying crops. These practices can be categorized according to the Efficiency-Substitution-Redesign framework of Hill and MacRae (1996). Efficiency practices (e.g., implementing precision agriculture) optimize pesticide use by increasing pesticide productivity without decreasing crop yields (Boussemart et al., 2013). Substitution practices replace pesticide use as much as possible while keeping crop yields constant; they are likely to have fewer negative impacts on the environment and human health (e.g., changing sowing dates, using resistant crop varieties and crop-variety mixtures, mechanical weed control, biocontrol). In a traditional microeconomic framework, the degree of substitution possible depends on relative prices of pesticides and opportunity costs of alternative practices (Sexton et al., 2007). Redesign practices combine alternative practices to pesticides, with an emphasis on prevention to place crops in the best possible condition while discouraging pests and diseases; they require profound changes in cropping systems (e.g., using intercropped service crops, extending crop rotations, diversifying crops) including changes in goals (e.g., lower crop yields).

Like any change in a practice, implementing alternative practices to reduce pesticide use influences how farmers work (Delecourt et al., 2019) by modifying the work to be done and the necessary resources and skills (Dedieu and Serviere, 2012). Effects of changing a practice on work depend on the nature of the practice itself and on the context (e.g., soil and weather conditions, production and strategic orientations) (Jacquot et al., 2020). For example, Jansen (2000) mentioned that mechanical weed control requires more working time and extending crop rotations may require more labor. Ridier et al. (2013) observed that crop diversification decreased labor productivity (i.e., amount produced per labor unit) but could also decrease labor peaks during the year. More generally, Lu et al. (2018) observed a significant relation between workforce (i.e., labor as an amount of production) and pesticide use: a decrease in the rural workforce in three Chinese provinces from 2001 to 2012 significantly increased the amount of pesticides applied to the provinces' cropland. Furthermore, alternative practices to reduce pesticide use require more time to monitor crops to take preventive actions. They also require greater accuracy to perform the necessary operations at the proper time (Delecourt et al., 2019; Jacquot et al., 2020; Girard and Magda, 2020).

This can be particularly challenging on livestock farms, especially dairy farms, which have strong work constraints due to routine work (e.g., daily herd care and milking; Fig. 1). For example, Tirard et al. (2020) assessed the amount of routine work on dairy farms in Brittany, France, as up to 30 h per week per labor unit in winter. The issue of reducing pesticide use is frequently studied from the perspective of the cropping system only. However, this approach fails to consider the organizational aspects of the farming system, which involves the simultaneous management of two systems, namely cropping and livestock, with strong interactions between them. Thus, reducing pesticide use on dairy farms cannot be considered without considering the livestock system, since they have a limited ability to reallocate working time from the livestock system to the cropping system (Servière et al., 2019; Delecourt et al., 2019).

These results raise the question of whether work limits implementation of alternative practices to reduce pesticide use on dairy farms, depending on the amount of change the practices require. The present study addressed this issue by considering three work dimensions: work organization, skills and knowledge, and physical and mental workload. This selection of dimensions was based on the findings of Delecourt et al. (2019), which indicated that these three work dimensions are important for farmers to implement changes in their practices. We assumed that if farmers organize their work appropriately (e.g., working time and machines available at the proper time), they would adopt efficiency or substitution practices rather than redesign practices. Indeed, the latter

are demanding in terms of skills and knowledge, as well as physical and mental workload (Chizallet et al., 2018; Mattila et al., 2022). Consequently, we assumed that these two work dimensions had more influence on the adoption of redesign practices.

To answer this question, we used dairy farms in Brittany, the most intensive livestock region of France, as a case study and interviewed a sample of nine regional experts who were used to dealing with farmers' concerns about managing crop protection. These interviews aimed to explore different viewpoints within the farm advisory system of farm work difficulties related to changing practices.

2. Materials and methods

2.1. Work dimensions

The dimension of work organization was defined by Corderoy and Parker (2008) as "the way tasks are organized and coordinated within the context of an overarching work system". Farming is characterized by high variability in agricultural activities over time due to animal and crop cycles, which implies seasonal variations in tasks and workload (Madelrieux and Dedieu, 2008). Crop scientists developed frameworks that identify potential time windows for performing seasonal work as a function of soil and climate constraints and workforce availability (e.g., Joannon et al., 2005). Livestock scientists developed frameworks to analyze the ability of livestock farms to address two time scales of work: routine and seasonal (e.g., Cournut et al., 2018). These frameworks consider work flexibility, defined as the time left for the workers to perform tasks besides routine and seasonal work (e.g., administration, maintenance) and save free time (Cournut et al., 2018). Work flexibility influences workers' ability to face risks, which tend to increase labor peaks, but also to think about changing practices and to train (Cournut et al., 2018). For example, Pardo et al. (2010) used a farming system model that integrated labor requirements to illustrate that certain practices associated with integrated weed management, including mechanical weed control and delayed autumn sowing, can result in labor constraints. We thus assumed that adopting certain alternative practices to pesticide use (e.g., mechanical weed control, extending crop rotations, diversifying crops) generates more work and labor peaks. As the majority of the workforce is dedicated to animals, we assumed that more work and labor peaks may act as a limiting factor in the adoption of these alternative practices.

The dimension of skills and knowledge consists of human capital, based on the level of education, training and field experience, all of which can be increased by access to information, peer exchanges and advisor follow-ups (Meissle et al., 2010; Delecourt et al., 2019; Comer, 2021). For these reasons, skills and knowledge vary among farmers depending on factors such as their age, experience, social network and education. Coolsaet (2016) stated that agroecological practices are recognized as knowledge-intensive practices. Girard and Magda (2020) specified that for these practices, farmers must develop more generic knowledge and adapt it to their own situations. Delecourt et al. (2019) indicated that farmers require work-related information, particularly regarding working time, work organization, and skills and knowledge, to make informed decisions about and implement new agroecological practices. Similarly, we thus assumed that adopting certain alternative practices to pesticide use requires farmers to acquire new skills and knowledge.

The dimension of physical and mental workload is related to the concept of occupational well-being (Hansen et al., 2020; Contzen and Häberli, 2021). It includes the presence (or absence) of occupational health problems, the performance of (un)pleasant tasks and the perception of work-related (dis)advantages (including those of the crop and livestock practices chosen) (Dumont and Baret, 2017; Mattila et al., 2022). More precisely, mental workload is a polysemous term defined here as the cognitive work required to accomplish tasks in a finite period (Longo et al., 2022). Galy et al. (2012) indicated that an additive effect

of task difficulty and time pressure on mental workload is evident, resulting in increased mental workload. In the context of pesticide reduction, if we consider our previous assumptions regarding certain alternative practices as being more demanding in terms of work as well as skills and knowledge, we assumed that the mental workload increases when changing to more complex cropping systems, due to the need to observe crops more often and to intervene during narrower time windows.

2.2. Interview guide

To investigate how the three work dimensions limit implementation of alternative practices to pesticide use, we performed face-to-face interviews with regional crop and livestock experts. A semi-structured interview guide was designed to meet three objectives: (1) validate and supplement the list of alternative practices initially developed (i.e., implementing precision agriculture, changing sowing dates, using resistant crop varieties and crop-variety mixtures, mechanical weed control, biocontrol, extending crop rotations (including using intercropped service crops) and diversifying crops), (2) qualitatively assess the degree of pesticide reduction attainable through each practice and (3) identify difficulties in implementing each alternative practice (or combination of alternative practices). These difficulties can be influenced by the characteristics of a practice itself but also by a farm's environment and resources. The list of alternative practices was initially developed by the present authors based on their expertise and on the practices promoted in the ÉcoPhyto II+ plan (Ministère de la Transition écologique et solidaire, 2018) and presented in the EU study of Reinders et al. (2021). It was assumed that (i) these alternative practices can be implemented in dairy farms for any arable crops and (ii) they act differently on work.

To meet objective 1, we presented the Efficiency-Substitution-Redesign framework to the experts and asked them to validate the categorization of each alternative practice in it. During interviews, experts were allowed to add or remove practices. For each alternative practice, experts had to justify their (i) categorization of each alternative practice in the framework and (ii) addition or removal of practices. The questions we asked to learn about their justifications were deliberately open and not oriented towards work dimensions in order not to miss any factors that influence implementation of alternative practices. To meet objectives 2 and 3, the experts were asked to consider implementation of each alternative practice alone on a conventional Brittany dairy farm (i.e., with a crop rotation based on grassland, maize and winter wheat). We asked them to assess on a set of axes the effectiveness of each practice in reducing pesticide use and its associated difficulties.

2.3. Panel of experts interviewed

Since experts may have different opinions about reducing pesticide use, we interviewed nine experts who belonged to different institutions (Table 1). Indeed, as explained by Aujas et al. (2011) regarding integrated farming, the background and type of advice depend on an advisor's institution. They found that advisors from cooperatives and trading institutions prioritized efficiency practices over substitution or redesign practices and that the decision support tools generally promoted did not favor redesign practices. In line with these results, we developed a panel of experts who could have different viewpoints in farm advising. Some of the experts had a direct connection to the field, such as coordinators of farmers' groups engaged in reducing pesticide use. Others had a more distant connection to the field but were chosen for their ability to consider objectively the issue of reducing pesticide use.

Specifically, experts A, B and C were agricultural advisors who belonged to a farmers' cooperative that supplied inputs (e.g., seeds, fertilizers, pesticides) and purchased agricultural goods, while expert F was a manager of the French Western Cooperative Union, whose role is to federate and represent the cooperatives in western France (Table 1).

Table 1

The nine experts interviewed, the organization they belonged to, their function, and their main contacts.

Category of organization	Name of organization	Function within the organization	In direct contact with:	Code
Farmers' cooperative	Farmers' cooperative group	Advisors	Farmers	A
		supervising “30,000 groups” ^{**}		B
		Administrative head of the union		C
Research and development institute	French Western Cooperative Union	Local project manager	–	F
		Agricultural technical institute for oilseeds and protein crops	Advisors	D
		Agricultural technical institute for cereals and forages	Advisors	E
Chamber of Agriculture	Brittany Chamber of Agriculture	Advisor supervising a DEPHY FERME group [†]	Farmers	H
ONVAR*	Farmers' non-profit organization to promote agriculture and rural development	Advisor supervising farmers' groups	Farmers	G
		Local team leader of advisors of DEPHY FERME groups	Advisors	I

* Recognized by the French Ministry of Agriculture as part of the ÉcoPhyto plan, a “30,000 group” consists of volunteer farmers who implement alternative practices to pesticides on their farms that have already been tested by other groups (including DEPHY FERME groups).

† Recognized by the French Ministry of Agriculture as part of the ÉcoPhyto plan, a DEPHY FERME group consists of volunteer farmers who test alternative practices to pesticide use on their farms with the help of an advisor of the DEPHY FERME network.

‡ In French, Organisme National à Vocation Agricole et Rurale: a farmer-based organization, often grounded in collective and participatory approaches, as well as promotion of alternative farming practices or models of farm management.

Experts D and E were project managers who belonged to national research and development institutes specialized in crops; they were in charge of scientific and applied expertise but did not advise farmers directly. Expert H belonged to the Brittany Chamber of Agriculture, coordinating farmers in the DEPHY FERME network (see Table 1 for a definition of this network). Experts G and I belonged to a non-profit organization that promotes alternative farming practices in two areas of Brittany. This organization bases its advice services on farmers' decision-making autonomy through information exchanges in farmers' groups.

2.4. Data collection and analysis

Face-to-face interviews were performed in April and May 2022, each lasting ca. 1.5 h. The interviews were audio recorded and transcribed. The objective was to perform a thematic analysis of the transcripts in order to identify the experts' assessments of the efficiency of each alternative practice and the main difficulties in implementing them, including those related to work dimensions. To this end, the relevant statements from the experts' transcripts were coded with headings and manually classified in a thematic analysis grid based on our framework (i.e., the Efficiency-Substitution-Redesign category of each alternative practice, its efficiency, and its difficulties in implementing it). The grid was supplemented by emerging ideas from the transcripts. This method enables a comparison across the interviews to identify overarching themes and to reflect the diversity of points of view. In particular, we identified the difficulties stated by experts in implementing three specific practices in relation to the three work dimensions – using resistant

crop varieties, mechanical weed control and extending crop rotations. We decided to focus the analysis on these specific practices because (i) using resistant crop varieties and extending crop rotations were the most frequently mentioned alternative practices by experts (five out of nine and eight out of nine, respectively) and mechanical weed control is the alternative practice most promoted by the *ÉcoPhyto II+* plan (Ministère de la Transition écologique et solidaire, 2018). The experts' comments included in this article were translated into English.

3. Results and discussion

3.1. Experts' assessments of alternative practices to reduce pesticide use

The experts interviewed did not question the alternative practices identified for dairy farms or suggest any new ones. The experts discussed all practices, regardless of their categorization in the Efficiency-Substitution-Redesign framework. However, they generally paid more attention to efficiency and substitution practices, likely because they are less risky, although they are less effective at reducing pesticide use (Guyomard et al., 2020). Experts G and I noted that high interest payments limit farmers' ability to adopt redesign practices due to the greater exposure to financial risks.

The experts agreed that the most effective practices for reducing pesticide use were mechanical weed control and extending crop rotations, which were also both the most difficult for farmers to implement (Fig. 2). Overall, however, they considered that the other alternative practices to pesticides (i.e., changing sowing dates, using resistant crop varieties and crop-variety mixtures, biocontrol) were moderately effective and simple to implement. Opinions about precision agriculture

were more clear-cut: some considered it to be relatively effective, while others considered it to be completely ineffective.

Overall, their assessments agreed with an EU study (Reinders et al., 2021) that identified the potential impact of each practice on weed, disease and insect control. The only points of disagreement were about using resistant crop varieties and precision agriculture, which the EU study considered to have high potential.

3.1.1. Experts from farmers' cooperatives discussed mechanical weed control, extending crop rotations and diversifying crops

All three experts from farmers' cooperatives (experts A, B and C) were skeptical about farmers' ability to use mechanical weed control to reduce pesticide use. Although all of them considered it relevant for this purpose, it requires suitable climatic conditions (even more so than pesticides do), appropriate weeding equipment and training ("[It is] very very dependent on weather conditions. [...] In bad years, it is difficult to implement; one needs the appropriate equipment, soil [and] climate. [...] In 2021, it rained all June long, and weeds grew back." (Expert A)). This is consistent with some well-known negative aspects of mechanical weed control (e.g., "highly dependent on weather and soil conditions and correct time of application [and it requires] skilled labor." (Hussain et al., 2018)). To address this issue, the experts mentioned that farmers can outsource mechanical weed control, either partially (equipment alone) or completely (equipment plus a skilled workforce), but in either case, the farmers decide whether or not to weed. In France, two types of companies provide such outsourcing for farmers: CUMA (in French, Coopérative d'Utilisation du Matériel Agricole; a cooperative that makes agricultural equipment available to its members) and ETA (in French, Entreprise de Travaux Agricoles; a contracting business that farmers pay to perform field work). As expert B noted, "[It's] one of the first means. [...] CUMA and ETA have the proper equipment...but farmers need to be trained; someone has to show them, and voilà". In addition, the experts did not see themselves recommending this type of practice ("We are here to guide those who want to change. [...] The farm advisor is a field observer; it's the farmer who decides whether [management is] chemical or mechanical." (Expert C)).

Experts A, B, C and F considered extending crop rotations and diversifying crops (including grassland) as effective at reducing pesticide use, but they did mention obstacles. First, adding new species to crop rotations can introduce new diseases, some of which are difficult to control (e.g., soil-borne diseases hosted by grain legumes; Wacker and Dresbøll (2023)) (experts C and F). Second, expert F mentioned the difficulty that cooperatives have collecting products from a few farmers ("Our organizations are collecting and processing (agricultural goods). When a farmer redesigns his farming system – and consequently can no longer supply milk in summer, for instance – it is all right at the individual scale. But it makes sense only if your neighbor, another dairy farmer, still provides milk for the dairy"). This usually occurs when dairy farmers decide to base their feeding system only on grass by matching the herd's feed demand to the dynamics of grassland production by having their cows calve in spring (Horan et al., 2019). This practice has three main consequences: i) an advantage for farmers since pesticide use decreases greatly (e.g., Lechenet et al., 2016) due to the high proportion of grassland in the farm area, ii) a seasonal workload with large labor peaks in spring and summer and a lower workload in winter (Hogan et al., 2023) and iii) a disadvantage for cooperatives since milk production stops in winter.

3.1.2. Experts from research and development institutes discussed high-tech practices

Experts D and E focused their assessment of alternative practices on precision agriculture and discussed the use of decision support tools to advise farmers ("[For decision support tools] as technical institutes, we are very specialized, in the sense that we provide many mechanistic crop models that can predict all steps of the spread of diseases; we also have statistical models since we collect a lot of data." (Expert E)). They

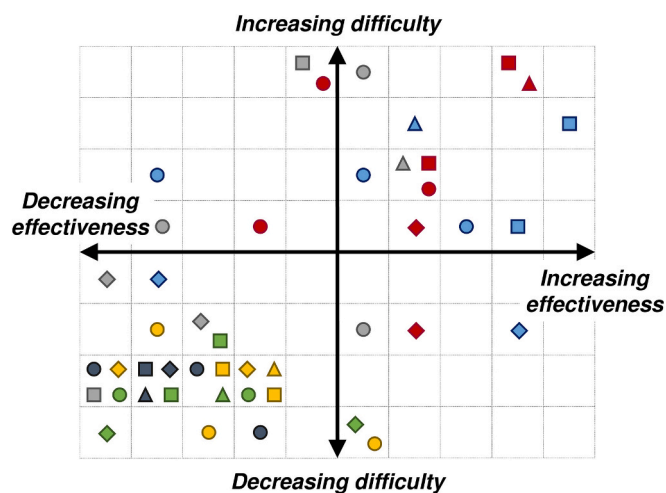


Fig. 2. Relative effectiveness in reducing pesticide use (x-axis) and difficulty of implementation for farmers (y-axis) of alternative practices to pesticide use (i.e., implementation of precision agriculture (gray), changing sowing dates (green), using resistant crop varieties and crop-variety mixtures (yellow), mechanical weed control (blue), biocontrol (black) and extending crop rotations (red)) according to eight experts (A to I, except F). In accordance with Table 1, the circles represent experts from farmers' cooperatives, the squares represent experts from research and development institutes, the triangles represent the expert from the Chamber of Agriculture, and the diamonds represent experts from non-profit organizations (ONVAR). When an expert's assessment of a practice was nuanced (e.g., ineffective in one situation but effective in another), we kept the most optimistic assessment of effectiveness and most pessimistic assessment of difficulty. Due to a lack of assured technical knowledge, experts D and G did not assess biocontrol, expert C did not assess changing sowing dates. Due to the nature of his function, expert F is not in direct interaction with farmers and lacks a high level of technical knowledge. Consequently, expert F did not contribute to the detailed assessment of the effectiveness and difficulty of any practice. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

highlighted that farmers have limited ability to implement precision agriculture and use decision support tools because they require high investment and training, a limit that other studies have identified (e.g., [Walter et al., 2017](#); [Schnebelin et al., 2021](#); [Lucas and Gasselín, 2022](#)). The experts suggested that dissemination could be eased by companies such as CUMA and ETA, which have larger capacities and economies of scale for financial and human investment (“In CUMA and ETA, they are aware of technological updates, and there are no obstacles. For farmers who have to manage alone, it depends on whether they are into new technologies. Some will train themselves and deeply explore how to use these technologies. Others will need guidance and advice.” (Expert E); “The equipment is not very widespread, and it is expensive. It is more affordable for CUMA and ETA than for farmers.” (Expert C)). According to [Nguyen et al. \(2020\)](#) and [Schnebelin \(2022\)](#), outsourcing is a way to access digital devices and high-tech practices by decreasing investment by individual farms.

3.1.3. Experts from the Chamber of Agriculture and non-profit organization discussed redesign practices

Both experts from the non-profit organization focused on redesign practices (“Precision agriculture has a limited potential for livestock farms; it is better to redesign the farm system, [and] it is easier. [...] With livestock, grassland is possible (in rotations), but you can’t do this on specialized crop farms.” (Expert I); “[Precision agriculture] is related to relatively huge investments, and I think this is an obstacle. It gives an opportunity to favor investment, but I think it doesn’t change the world concerning pesticides” (Expert G)). Although these experts clearly recommended redesign practices, they did not ignore the difficulties in implementing them: (i) the risk of losing income due to converting land from crops to grassland and (ii) the investment in human capital required (“It requires new knowledge and know-how, so it is not easy.” (Expert G)). For French field crops, [Jacquet et al. \(2011\)](#) showed that implementing efficiency and substitution practices could reduce pesticide use by up to 30 % without reducing farmers’ gross margins. They also demonstrated that reducing pesticide use by 50 % requires implementing redesign practices such as extending crop rotations, diversifying crops and changing farming system objectives.

3.1.4. Conclusion about experts’ assessments of alternative practices to reduce pesticide use

Even if the experts interviewed did not question the alternative practices identified, they tended to emphasize certain alternative practices over others, depending on the institution to which they belonged as observed by [Aujas et al. \(2011\)](#). The experts interviewed seemed well aware of alternative practices, which enabled them to be disseminated. All experts in direct contact with farmers also emphasized that the practices chosen, regardless of their category, remain the farmers’ decision and depend on their individual desires and paths (“It is up to farmers to make their own way.” (Expert B)).

3.2. Experts’ assessments of specific difficulties that dairy farms face in implementing alternative practices to pesticide use

3.2.1. Influence of the feeding system

Expert H specified that designing strategies to reduce pesticide use without considering livestock systems is ineffective: “The more animals the farmer owns, the less time he can spend on cropping systems, and the less he is willing to change practices. [...] It really affects pesticide use... because if you don’t modify the livestock system, you don’t modify the cropping system.” All nine experts agreed that the feeding system is a key factor that influences the difficulties that farmers experience implementing redesign practices in the field. In fact, some farmers can orient their feeding system towards more grazing, which allows for redesign practices such as extending crop rotations to include grassland (“The proportion of maize is related to a strategy. Those who do not rely on maize as much and are looking for [feed and forage] self-

sufficiency...may have a little more...legume crops [in their crop rotation and] use less feed inputs..., and those who have a large proportion of maize...are looking more to optimize [livestock] performances of the dairy herd.” (Expert E)). This result is consistent with that of [Becker et al. \(2018\)](#), who observed that perceptions of advantages and disadvantages of grazing systems differed between dairy farmers whose farms had or did not have grassland.

3.2.2. Influence of the milking system

Six of the nine experts mentioned that an automated milking system influences the feeding system and thus the cropping system. They considered that with an automated milking system the feeding system would less likely be grazing-based (“Dairy farms with an automated milking system in which cows do not go out...; frankly, you do not choose the same crops...as those who...base their system on grazing.” (Expert C)). According to four experts, this potential incompatibility can be partially overcome if grasslands are accessible to cows for grazing and not too far from the barn. Reviews of [Jacobs and Siegford \(2012\)](#) and [John et al. \(2016\)](#) were not as negative about incorporating automated milking systems into grassland-based systems: they reported studies in which the distance between the grassland and the barn did not influence the system’s success, but they highlighted that a well-functioning cow traffic system is essential. Reviews of [Martin et al. \(2022\)](#) identified that in several countries (e.g., France, Norway), herd size increased when farms transitioned to automated milking. It also increases milk productivity to achieve economies of scale ([Vik et al., 2019](#)), but it is not highly compatible with a grazing system.

3.2.3. Influence of farm structure

Experts disagreed on the influence of farm structure. Experts D and E considered that having a large farm is likely to favor reducing pesticide use, due to the cost and time saved when a farmer does not have to apply them. In contrast, experts G and I considered that it is easier to implement alternative practices on small farms. [Galliano and Siqueira \(2021\)](#) also observed this disagreement. Some studies highlighted the ability of large farms to experiment with new practices on a small proportion of their area and gradually adopt them on the entire area ([Chouinard et al., 2016](#)). Others considered that small and less intensive farms are more likely to adopt alternative practices ([Vanslembrouck et al., 2002](#)). Besides size, six experts emphasized the key role of the ratio of farm area (or herd size) to the workforce. For these experts, labor productivity determines farmers’ ability to free up time for time-consuming alternative crop protection practices; this is particularly true in Brittany, where the mean farm area increases each year ([Agréte, 2022](#)) (“They have a large farm area and no workforce...so they don’t have time.” (Expert B)). [Midler et al. \(2019\)](#) determined, based on French farm accountancy data, that dairy farms with higher environmental performances were also more labor-intensive.

3.3. Experts’ assessments of effects of the three alternative practices on the three work dimensions

We analyzed the experts’ assessments of the two substitution practices (using resistant crop varieties, mechanical weed control) and one redesign practice (extending crop rotations) on the three work dimensions (Table 2), since practices differ in their effects on work dimensions ([Jacquot et al., 2020](#)). The experts never mentioned physical or mental workload as an obstacle to change. They described “work” in only two senses: workload and skills/knowledge (“There is also the issue of stepping back: those who have too much work and no time to step back from their farm rush headlong into it. If they have time to think about their model, they can either stay with it because they want to, or change.” (Expert H)). A heavy workload implies that farmers would have difficulty finding time to step back and think about their system, train, visit other farmers, or exchange information about their practices despite the potential benefits of changing to alternative practices.

Table 2
Analysis of the experts' assessments of effects of implementation of three alternative practices to pesticides on three work dimensions.

Practice			
Work dimension	Using resistant crop varieties ("easy to implement")	Mechanical weed control ("difficult to implement")	Extending crop rotations ("implement in two steps")
Work organization		<ul style="list-style-type: none"> • Heavier workload than that of chemical control • Narrower weather windows than those of chemical control • Large investments in equipment or use of outsourcing to manage the workload 	<ul style="list-style-type: none"> • Increased workload if additional cash crop(s) included in the rotation • Reduced workload if grassland included in the rotation • Freeing up time to design the new rotation may conflict with daily activities (routine work)
Skills and knowledge	<ul style="list-style-type: none"> • Not mentioned by the experts • Information on characteristics of the crop varieties is required (this information exists and is provided to farmers by advisors) 	<ul style="list-style-type: none"> • Training is needed: <ul style="list-style-type: none"> – to recognize suitable conditions – to use weeding equipment properly 	<ul style="list-style-type: none"> • Gives farmers the means to think about new rotations
Physical and mental workload	<ul style="list-style-type: none"> • Not explicitly mentioned by the experts, but they did mention the need to plan the purchase of seeds 	<ul style="list-style-type: none"> • Not mentioned by the experts 	<ul style="list-style-type: none"> • Not mentioned by the experts

Besides workload as a limiting factor, [Delecourt et al. \(2019\)](#) also mentioned a lack of information for farmers about impacts of alternative practices on working time, mainly due to underestimating factors such as working time and difficulties in predicting the timing of operations.

3.3.1. Using resistant crop varieties

Seven of the nine experts considered that using resistant crop varieties was easy for farmers to implement ("One of the easiest practices to implement." (Expert A)). One advantage of using resistant crop varieties (to control pests and diseases) and competitive crop varieties (to suppress weeds) is that it does not require farmers to learn a completely new practice: they only need to change the seeds they sow (e.g., [Lowry and Smith, 2018](#)). To do so, five experts mentioned that farmers can easily find information about characteristics of crop varieties (e.g., disease tolerance), mainly from their advisors and cooperatives. For four of them, advisors play a key role in reassuring farmers and supporting their decisions to buy certain crop varieties. Nonetheless, three experts highlighted that this alternative practice requires that farmers plan work ("[Choosing a new variety] is possible only if you purchase earlier. [...] Harvests are not yet finished, but the farmer...needs to think about what...to grow next year. If he waits until the end of harvest...not all of the varieties he wants will be available." (Expert C)).

3.3.2. Mechanical weed control

Although mechanical weed control was recognized as the "spearhead" (Expert H) of alternative practices, six of the nine experts highlighted the difficulty for farmers of implementing it. Furthermore, all

experts agreed on the three major factors that hinder its implementation: i) heavier workload than that of chemical weed control; ii) more difficult work organization, with the need to perform operations during narrower weather windows than those for chemical weed control and iii) large investments for the appropriate equipment to speed up weeding ("[Mechanical weed control] means more power [and] a weeding tool that can work as fast as possible. Moreover, the soil must not be too muddy. [...] It requires more precision, within narrower time windows of suitable weather conditions. It means being able to timely allocate the workforce, adapted equipment with high throughput and skills in order to begin weeding." (Expert F)). In the same vein, the EU study ([Reinders et al., 2021](#)) showed that mechanical weed control usually required more tractor passes than chemical weed control, which increases physical and mental workload ([Mattila et al., 2022](#)) and labor peaks ([Pardo et al., 2010](#)). Eight of the nine experts emphasized that mechanical weed control is skill- and knowledge-intensive, requiring training to observe and recognize suitable conditions to implement it and properly use the equipment, depending on the objectives and the crop ("[Since it is] technically complicated, [farmers] must be trained and get used to the tool. Work on 10 meters, get out of the tractor, check, look at the results, adjust the tool settings, work on another 10 meters. Depending on the field, the crop and the weed, the setting won't be the same; [...] adjusting settings takes time." (Expert F)). Two experts emphasized the need for long-term advisory and support services to reassure farmers and facilitate experiments in fields and exchanges between farmers. For five of the nine experts, mechanical weed control can be disseminated effectively by outsourcing companies, which can afford the cost of weeding equipment and the need for training. These companies can train workers dedicated to this practice ("[Regarding the] feasibility [of mechanical weed control], French farm machinery cooperatives and agricultural contractors...have it." (Expert B); "[A practice] difficult to implement: performing the operation on time, accessing the tools, knowing how to properly use them; usually [best done by] French farm machinery cooperatives with drivers with special training." (expert H)). Thus, these experts considered that outsourcing companies, including local farm cooperatives, represent a powerful mechanism for changing practices through access to equipment, peer exchanges and access to training, as reported by [Lucas et al. \(2019\)](#).

3.3.3. Extending crop rotations

Experts differed in their assessments of extending crop rotations. Regarding the impacts on work organization and workload, four experts distinguished the addition of annual crops (more workload) from that of temporary grassland (less workload) ("But the more you extend your crop rotations, the heavier the workload is, unless you include multi-year crops [temporary grassland], even though you still need to mow [them]." (Expert H)). They also mentioned impacts of adding certain crop species to the rotation on reducing pesticide use ("[Extending crop rotations] can be great, but among recent examples I have seen of adding...faba beans [or] vegetables, they require pesticides. [...] But with grassland, alfalfa [or] sunflower, you reduce [pesticide use]." (Expert C)).

Five experts considered extending crop rotations in two steps, each with different effects on work dimensions: (i) the redesign and implementation itself and (ii) maintaining the new rotation over time. The first step was considered work- and knowledge-intensive for farmers, and it can be more difficult for dairy farmers to free up time due to routine work ("In a crop-livestock system, livestock will determine the work allocated to the cropping system, but it will also determine the amounts of inputs into cropping systems and thus farmers' ability to allocate working time to redesign crop rotations. In addition, crop rotations need to be consistent with livestock diets, especially forage, which can be a limitation [to the redesign]." (Expert H)). However, the second step was considered to require less work, even for new rotations that include cash crops, since labor peaks are spread throughout the year, as observed by [Ridier et al. \(2013\)](#) for cash-crop farms. The

distinction between these two steps was also made by Chizallet et al. (2018) for farmers' adoption of redesign practices.

For redesign practices in general, five of the nine experts suggested that a key to favoring implementation of a redesign practice is to facilitate farmers' mental work and orient them towards specific training (i. e., help them gain more decision-making autonomy). Expert G stated that placing work aspects in the center of farmers' reflections provides additional perspectives: "mechanical weed control...works very well, but it increases...workload a lot; so, I don't know if it's relevant to compare [it] to a redesign process that will take time at the beginning, but [with which]...at the end, the farmer will gain some work efficiency".

4. Conclusion

Reducing pesticide use on dairy farms cannot be separated from work management. Because of the heavy and constrained workload of livestock systems, it can be difficult to reallocate work from the livestock system to the cropping system to implement alternative practices that can be work-intensive. Alternative practices can also be knowledge-intensive and may incur additional mental workload. Thus, work, in its multiple dimensions, may be a factor, often forgotten, that limits implementation of alternative practices to reduce pesticide use, depending on the amount of change they require, particularly on dairy farms.

Most of the work difficulties that experts mentioned concerned work organization and skills and knowledge. They never mentioned mental workload as an obstacle to implementing alternative practices but did explicitly establish a relation between a heavy workload and farmers' ability to change practices. Focusing on two substitution practices (using resistant crop varieties, mechanical weed control) and one redesign practice (extending crop rotations), we found that, unsurprisingly, work organization was influenced more by redesign practices than by substitution practices, but only in the first step of the former. In the second step of redesign practices, work organization can be alleviated. The three practices are also all skill- and knowledge-intensive, but in different ways. Using resistant crop varieties implies having access to the necessary information (e.g., the level of resistance to a given pathogen or pest), while implementing mechanical weed control involves training, investment or outsourcing. Extending crop rotations implies having the means, time and autonomy to think about new rotations.

This study improves understanding of the main obstacles related to work issues of alternative practices in order to identify specific mechanisms or actions to help farmers implement them. This study contributes to the ongoing debate in the field of research on the adoption of alternative practices to pesticides, which is currently dominated by cost-effectiveness and behavioral factor studies (Finger et al., 2024). This study addresses an issue that has been insufficiently explored in this literature, offering new insights into farming systems approaches and their policy implications. Furthermore, the study confirms the importance of considering more structural factors in public policies, such as workload, skills and knowledge, and work organization (Thompson et al., 2024). For example, new public policies could take into account the employment criterion, both in terms of quantity and quality. At the EU level, this would necessitate the reopening of the debate on modulating subsidies from the Common Agricultural Policy in accordance with an employment criterion and on the most appropriate indicators to be used for this purpose. Furthermore, the new policies could provide support not only for the technical aspects of alternative practices to pesticides but also on but also for work-related aspects, for example by focusing on availability requirements so that farmers can attend training courses.

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CRedit authorship contribution statement

Julia Denantes: Writing – original draft, Methodology, Investigation, Formal analysis. **Anne-Lise Jacquot:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Matthieu Carof:** Writing – review & editing, Writing – original draft, Visualization, Methodology. **Carole Ropars-Collet:** Supervision, Methodology. **Aude Ridier:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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References

- Agreste, 2022. Recensement agricole 2020. Main-d'œuvre et externalisation des travaux. Une montée en puissance de la main-d'œuvre salariée. *Études Bretagne* 3, 1–4.
- Aujas, P., Lacroix, A., Lemarié, S., Reau, R., 2011. Réduire l'usage des pesticides. Un défi pour le conseil aux agriculteurs. *Econ. Rural.* 324, 18–33. <https://doi.org/10.4000/economierurale.3071>.
- Becker, T., Kayser, M., Tonn, B., Isselstein, J., 2018. How German dairy farmers perceive advantages and disadvantages of grazing and how it relates to their milk production systems. *Livest. Sci.* 214, 112–119. <https://doi.org/10.1016/j.livsci.2018.05.018>.
- Boussemart, J.-P., Leleu, H., Ojo, O., 2013. The spread of pesticide practices among cost-efficient farmers. *Environ. Model. Assess.* 18, 523–532. <https://doi.org/10.1007/s10666-013-9363-5>.
- Chauvel, B., Guillemin, J.-P., Gasquez, J., Gauvrit, C., 2012. History of chemical weeding from 1944 to 2011 in France: Changes and evolution of herbicide molecules. *Crop Prot.* 42, 320–326. <https://doi.org/10.1016/j.cropro.2012.07.011>.
- Chizallet, M., Barcellini, F., Prost, L., 2018. Supporting farmers' management of change towards agroecological practices by focusing on their work: a contribution of ergonomics. *Cah. Agric.* 27, 35005. <https://doi.org/10.1051/cagri/2018023>.
- Chouinard, H.H., Wandschneider, P.R., Paterson, T., 2016. Inferences from sparse data: An integrated, meta-utility approach to conservation research. *Ecol. Econ.* 122, 71–78. <https://doi.org/10.1016/j.ecolecon.2015.11.019>.
- Cisternas, I., Velásquez, I., Caro, A., Rodríguez, A., 2020. Systematic literature review of implementations of precision agriculture. *Comput. Electron. Agric.* 176, 105626. <https://doi.org/10.1016/j.compag.2020.105626>.
- Comer, C., 2021. Des repreneuses d'exception ? Le rôle des parcours scolaires. *Nouv. Rev. Trav.* 18. <https://doi.org/10.4000/nrt.8118>.
- Contzen, S., Häberli, I., 2021. Exploring dairy farmers' quality of life perceptions – A Swiss case study. *J. Rural Stud.* 88, 227–238. <https://doi.org/10.1016/j.jrurstud.2021.11.007>.
- Coolsaet, B., 2016. Towards an agroecology of knowledges: Recognition, cognitive justice and farmers' autonomy in France. *J. Rural Stud.* 47, 165–171. <https://doi.org/10.1016/j.jrurstud.2016.07.012>.
- Cordery, J., Parker, S.K., 2008. Work organization. In: Boxall, P., Purcell, J., Wright, P.M. (Eds.), *The Oxford Handbook of Human Resource Management*. Oxford University Press, Oxford (United Kingdom), pp. 187–209.
- Cournut, S., Chauvat, S., Correa, P., et al., 2018. Analyzing work organization on livestock farm by the work assessment method. *Agron. Sustain. Dev.* 38, 58. <https://doi.org/10.1007/s13593-018-0534-2>.
- Dedieu, B., Serviere, G., 2012. Vingt ans de recherche-développement sur le travail en élevage : acquis et perspectives. *INRAE Prod. Anim.* 25, 85–100. <https://doi.org/10.20870/productions-animales.2012.25.2.3200>.
- Delecourt, E., Joannon, A., Meynard, J.-M., 2019. Work-related information needed by farmers for changing to sustainable cropping practices. *Agron. Sustain. Dev.* 39, 28. <https://doi.org/10.1007/s13593-019-0571-5>.
- Dumont, A.M., Baret, P.V., 2017. Why working conditions are a key issue of sustainability in agriculture? A comparison between agroecological, organic and conventional vegetable systems. *J. Rural Stud.* 56, 53–64. <https://doi.org/10.1016/j.jrurstud.2017.07.007>.

- Finger, R., Sok, J., Ahovi, E., et al., 2024. Towards sustainable crop protection in agriculture: A framework for research and policy. *Agric. Syst.* 219, 104037. <https://doi.org/10.1016/j.agry.2024.104037>.
- Gaba, S., Lescourret, F., Boudsocq, S., et al., 2015. Multiple cropping systems as drivers for providing multiple ecosystem services: from concepts to design. *Agron. Sustain. Dev.* 35, 607–623. <https://doi.org/10.1007/s13593-014-0272-z>.
- Galliano, D., Siqueira, T.T.S., 2021. Organizational design and environmental performance: The case of French dairy farms. *J. Environ. Manage.* 278, 111408. <https://doi.org/10.1016/j.jenvman.2020.111408>.
- Galy, E., Cariou, M., Mélan, C., et al., 2012. What is the relationship between mental workload factors and cognitive load types? *Int. J. Psychophysiol.* 83, 269–275. <https://doi.org/10.1016/j.ijpsycho.2011.09.023>.
- Gardarin, A., Celette, F., Naudin, C., et al., 2022. Intercropping with service crops provides multiple services in temperate arable systems: a review. *Agron. Sustain. Dev.* 42, 39. <https://doi.org/10.1007/s13593-022-00771-x>.
- Girard, N., Magda, D., 2020. The interplays between singularity and genericity of agroecological knowledge in a network of livestock farmers. *J. Rural. Stud.* 73, 214–224. <https://doi.org/10.1016/j.jrurstud.2019.11.003>.
- Guyomard, H., Bureau, J.-C., Chatellier, V., et al., 2020. Research for AGRI Committee – The Green Deal and the CAP: Policy Implications to Adapt Farming Practices and to Preserve the EU's Natural Resources. European Parliament, Policy Department for Structural and Cohesion Policies, Brussels (Belgium).
- Hansen, B.G., Bugge, C.T., Skibrek, P.K., 2020. Automatic milking systems and farmer wellbeing—exploring the effects of automation and digitalization in dairy farming. *J. Rural Stud.* 80, 469–480. <https://doi.org/10.1016/j.jrurstud.2020.10.028>.
- Hill, S.B., MacRae, R.J., 1996. Conceptual framework for the transition from conventional to sustainable agriculture. *J. Sustain. Agric.* 7, 81–87. https://doi.org/10.1300/J064v07n01_07.
- Hogan, C., Kinsella, J., Beecher, M., O'Brien, B., 2023. The impact of work organisation on the work life of people on pasture-based dairy farms. *Animal* 17, 100686. <https://doi.org/10.1016/j.animal.2022.100686>.
- Horan, B., Roche, J.R., Horan, B., Roche, J.R., 2019. Defining resilience in pasture-based dairy-farm systems in temperate regions. *Animal Prod. Sci.* 60, 55–66. <https://doi.org/10.1071/AN18601>.
- Hossard, L., Guichard, L., Pelosi, C., Makowski, D., 2017. Lack of evidence for a decrease in synthetic pesticide use on the main arable crops in France. *Sci. Total Environ.* 575, 152–161. <https://doi.org/10.1016/j.scitotenv.2016.10.008>.
- Hussain, M., Farooq, S., Merfield, C., Jabran, K., 2018. Chapter 8 - mechanical weed control. In: Jabran, K., Chauhan, B.S. (Eds.), *Non-chemical Weed Control*. Academic Press, pp. 133–155.
- Jacobs, J.A., Siegford, J.M., 2012. Invited review: The impact of automatic milking systems on dairy cow management, behavior, health, and welfare. *J. Dairy Sci.* 95, 2227–2247. <https://doi.org/10.3168/jds.2011-4943>.
- Jacquet, F., Butault, J.-P., Guichard, L., 2011. An economic analysis of the possibility of reducing pesticides in French field crops. *Ecol. Econ.* 70, 1638–1648. <https://doi.org/10.1016/j.ecolecon.2011.04.003>.
- Jacquet, A.-L., Gérard, M., Duval, J., Hostiou, N., 2020. Quels effets sur le travail des éleveurs bovins laitiers de l'adoption de pratiques agroécologiques dans l'Ouest de la France ? In: 3R 2020. Paris (France), pp. 1–5.
- Jansen, K., 2000. Labour, livelihoods and the quality of life in organic agriculture in Europe. *Biological Agric. Hortic.* 17, 247–278. <https://doi.org/10.1080/01448765.2000.9754845>.
- Joannon, A., Papy, F., Martin, P., Souchère, V., 2005. Planning work constraints within farms to reduce runoff at catchment level. *Agric. Ecosyst. Environ.* 111, 13–20. <https://doi.org/10.1016/j.agee.2005.04.021>.
- John, A.J., Clark, C.E.F., Freeman, M.J., et al., 2016. Review: Milking robot utilization, a successful precision livestock farming evolution. *Animal* 10, 1484–1492. <https://doi.org/10.1017/S1751731116000495>.
- Jokanović, M., 2018. Neurotoxic effects of organophosphorus pesticides and possible association with neurodegenerative diseases in man: a review. *Toxicol.* 410, 125–131. <https://doi.org/10.1016/j.tox.2018.09.009>.
- Lechenet, M., Makowski, D., Py, G., Munier-Jolain, N., 2016. Profiling farming management strategies with contrasting pesticide use in France. *Agr. Syst.* 149, 40–53. <https://doi.org/10.1016/j.agry.2016.08.005>.
- Longo, L., Wickens, C.D., Hancock, G., Hancock, P.A., 2022. Human mental workload: A survey and a novel inclusive definition. *Front. Psychol.* 13, 883321. <https://doi.org/10.3389/fpsyg.2022.883321>.
- Lowry, C.J., Smith, R.G., 2018. Chapter 5 - weed control through crop plant manipulations. In: Jabran, K., Chauhan, B.S. (Eds.), *Non-chemical Weed Control*. Academic Press, pp. 73–96.
- Lu, H., Xie, H., Chen, Q., Jiang, J., 2018. Impact of agricultural labor transfer and structural adjustment on chemical application: Comparison of past developments in the ecological civilization pilot zones of China and their future implications. *Sustain.* 10, 1909. <https://doi.org/10.3390/su10061909>.
- Lucas, V., Gasselín, P., 2022. An intensive and collective style of farm work that enables the agroecological transition: A case study of six French farm machinery cooperatives. *Front. Sustain. Food Syst.* 6, 862779. <https://doi.org/10.3389/fsufs.2022.862779>.
- Lucas, V., Gasselín, P., Van Der Ploeg, J.D., 2019. Local inter-farm cooperation: A hidden potential for the agroecological transition in northern agricultures. *Agroecol. Sustain. Food Syst.* 43, 145–179. <https://doi.org/10.1080/21683565.2018.1509168>.
- MacLaren, C., Storkey, J., Menegat, A., et al., 2020. An ecological future for weed science to sustain crop production and the environment. A review. *Agron. Sustain. Dev.* 40, 24. <https://doi.org/10.1007/s13593-020-00631-6>.
- Madelrieux, S., Dedieu, B., 2008. Qualification and assessment of work organisation in livestock farms. *Animal* 2, 435–446. <https://doi.org/10.1017/S175173110700122X>.
- Martin, T., Gasselín, P., Hostiou, N., et al., 2022. Robots and transformations of work in farm: a systematic review of the literature and a research agenda. *Agron. Sustain. Dev.* 42, 66. <https://doi.org/10.1007/s13593-022-00796-2>.
- Mattila, T.E.A., Perkiö-Mäkelä, M., Hirvonen, M., et al., 2022. Work exposures and mental and musculoskeletal symptoms in organic farming. *Ergonomics* 65, 242–252. <https://doi.org/10.1080/00140139.2021.1974102>.
- Meissle, M., Mouron, P., Musa, T., et al., 2010. Pests, pesticide use and alternative options in European maize production: current status and future prospects. *J. Appl. Entomology* 134, 357–375. <https://doi.org/10.1111/j.1439-0418.2009.01491.x>.
- Midler, E., Depeyrot, J.-N., Detang-Dessendré, C., 2019. Performance environnementale des exploitations agricoles et emploi. *Centre d'Études et de Prospectives 2019 n° 14*, 1–35.
- Ministère de la Transition écologique et solidaire, 2018. Plan Écophyto II+. La Défense (France).
- Nguyen, G., Brailly, J., Purseigle, F., 2020. Strategic outsourcing and precision agriculture: towards a silent reorganization of agricultural production in France ?. In: *Annual Meeting of the Allied Social Sciences Association (ASSA)*. San Diego (United States), p 41 p.
- Pannacci, E., Lattanzi, B., Tei, F., 2017. Non-chemical weed management strategies in minor crops: A review. *Crop Prot.* 96, 44–58. <https://doi.org/10.1016/j.cropro.2017.01.012>.
- Pardo, G., Riravololona, M., Munier-Jolain, N.M., 2010. Using a farming system model to evaluate cropping system prototypes: Are labour constraints and economic performances hampering the adoption of integrated Weed Management? *Eur. J. Agron.* 33, 24–32. <https://doi.org/10.1016/j.eja.2010.02.003>.
- Reinders, M., Riemens, M., Bremmer, J., 2021. The Future of Crop Protection in Europe. European Parliament, Directorate-General for Parliamentary Research Services. Publications Office of the European Union, Brussels (Belgium).
- Ridier, A., Ben El Ghali, M., Nguyen, G., Kephaliacos, C., 2013. The role of risk aversion and labor constraints in the adoption of low input practices supported by the CAP green payments in cash crop farms. *Rev. Études Agric. Environ.* 94, 195–219. <https://doi.org/10.4074/S1966960713012024>.
- Rigal, S., Dakos, V., Alonso, H., et al., 2023. Farmland practices are driving bird population decline across Europe. *Proc. National Acad. Sci. USA* 120, e2216573120. <https://doi.org/10.1073/pnas.2216573120>.
- Schnebelin, É., 2022. Linking the diversity of ecologisation models to farmers' digital use profiles. *Ecol. Econ.* 196, 107422. <https://doi.org/10.1016/j.ecolecon.2022.107422>.
- Schnebelin, É., Labarthe, P., Touzard, J.-M., 2021. How digitalisation interacts with ecologisation? Perspectives from actors of the French agricultural innovation system. *J. Rural Stud.* 86, 599–610. <https://doi.org/10.1016/j.jrurstud.2021.07.023>.
- Servière, G., Chauvat, S., Hostiou, N., Cournot, S., 2019. Le travail en élevage et ses mutations. *INRAE Prod. Anim.* 32, 13–24. <https://doi.org/10.20870/productions-animales.2019.32.1.2418>.
- Sexton, S.S., Lei, Z., Zilberman, D., 2007. The economics of pesticides and pest control. *Int. Rev. Environ. Resour. Econ.* 1, 271–326. <https://doi.org/10.1561/101.00000007>.
- Syed Ab Rahman, S.F., Singh, E., Pieterse, C.M.J., Schenk, P.M., 2018. Emerging microbial biocontrol strategies for plant pathogens. *Plant Sci.* 267, 102–111. <https://doi.org/10.1016/j.plantsci.2017.11.012>.
- Thompson, B., Leduc, G., Manevska-Tasevska, G., et al., 2024. Farmers' adoption of ecological practices: A systematic literature map. *J. Agr. Econ.* 75, 84–107. <https://doi.org/10.1111/1477-9552.12545>.
- Tirard, S., Abgrall, N., Bodin, T., Follet, D., 2020. Travail d'astreinte en hiver et au printemps en élevage laitier. *Chambre d'agriculture de Bretagne, Rennes, France*.
- Urruty, N., Deveaud, T., Guyomard, H., Boiffin, J., 2016. Impacts of agricultural land use changes on pesticide use in French agriculture. *Eur. J. Agron.* 80, 113–123. <https://doi.org/10.1016/j.eja.2016.07.004>.
- Vanslebrouck, I., Van Huylenbroeck, G., Verbeke, W., 2002. Determinants of the willingness of Belgian farmers to participate in agri-environmental measures. *J. Agr. Econ.* 53, 489–511. <https://doi.org/10.1111/j.1477-9552.2002.tb00034.x>.
- Vik, J., Straete, E.P., Hansen, B.G., Nærland, T., 2019. The political robot – the structural consequences of automated milking systems (AMS) in Norway. *NJAS - Wageningen J. Life Sci.* 90–91. <https://doi.org/10.1016/j.njas.2019.100305>, 100305.
- Wacker, T.S., Dresboll, D.B., 2023. Checking the pulse: perspectives on grain legume production. *Trends Plant Sci.* <https://doi.org/10.1016/j.tplants.2023.06.004>.
- Walter, A., Finger, R., Huber, R., Buchmann, N., 2017. Smart farming is key to developing sustainable agriculture. *Proc. National Acad. Sci. USA* 114, 6148–6150. <https://doi.org/10.1073/pnas.1707462114>.
- Way, M.J., van Emden, H.F., 2000. Integrated pest management in practice — pathways towards successful application. *Crop Prot.* 19, 81–103. [https://doi.org/10.1016/S0261-2194\(99\)00098-8](https://doi.org/10.1016/S0261-2194(99)00098-8).
- Wuest, S.E., Peter, R., Niklaus, P.A., 2021. Ecological and evolutionary approaches to improving crop variety mixtures. *Nat. Ecol. Evol.* 5, 1068–1077. <https://doi.org/10.1038/s41559-021-01497-x>.