Robots and Transformations of Work on Farms: A Systematic Review

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Abstract: *Agricultural robots are promoted as a solution to satisfy a growing demand for products while minimizing resource use. Following the recent development of the industry of farming robotics, we question how these technologies transform agriculture in a critical way. We carried out a systematic review of literature questioning the transformations of work related to robot's adoption in agriculture. The scope encompasses a wide range of disciplines of social science and farm engineering. We consider four aspects of work: i. the farm structures and the labour market; ii. the technical-economic performances; iii. the organization of work; iv. the meaning of work. We also have a particular focus on Automatic Milking System (AMS) and we discuss the vivid controversies about which farms adopt them. Concerning the relationship between labour time and the AMS adoption, we highlight a gap between measurements and perceptions by farmers. While economics studies indicate a significant reduction, farmers observe an increase of their labour time. AMS also induces deep qualitative transformations in work organization: a scattering of duties through the day time and a global reordering of tasks on the farm. AMS increases work flexibility and changes farmers' life-styles but also produces mental workload and stress. Changes in animal-human relationship question the possibility of new identities and new self-perceptions by farmers and workers. We highlight two gaps that could be explored by further research: how the notion of digital labour in agriculture could lead to news ways of analysing work; and how adoption of robots reshapes the landscape of collective organisations of farmers.*

Keywords: *agriculture, livestock, labour, automation, AMS*

Introduction

For a long time, the robotization of agriculture has been the subject of studies trying to automate agricultural tasks that are often arduous (Kawamura AND Namikawa, 1989). Since the late 1990s in Western and Northern Europe, many dairy farms have introduced automated milking system. Furthermore, nowadays new stakeholders arrive in the agricultural sector such as start-ups and venture capitalists (Rotz *et al.*, 2019). They are following – or encouraging - a movement of digital revolution in agriculture (Himesh *et al.*, 2018), which represents a promising market. After dairy farming, new agricultural sectors are affected by robotics such as aquaculture, horticulture, vine-growing or field crops (Duckett *et al.*, 2018). Robots are being promoted as a way to produce more while minimizing resource use, especially labour in a context of labour shortage (Reddy *et al.*, 2016; Rotz *et al.*, 2019).

The particularity of recent robots with regard to the history of the mechanization of agriculture lies in its capacity to carry out non-standardized tasks (Marinoudi *et al.*, 2019). It is also object of many hopes and fears about substitution of human labour. Behind the question of jobs lost and gained there are many questions about work transformations at farm level. Work is a complex subject studied by different scientific communities and disciplines (Malanski *et al.*, 2019). We propose to question the transformations of work on farms after robot's adoption through a systematic review. After defining what we consider to be a robot in agriculture, we present the research and selection strategies. The results are structured according to our work analysis framework. Finally the discussion allows us to identify a research agenda for further researches on work transformations with the adoption of robots on farms.

What is and what is not a robot?

Our research strategy results from what we consider to be a robot in agriculture. As there is no shared definition of a robot in agriculture in the literature, we propose our definition adapted to our subject of study. For more elements related to this definition, please read the published protocol (Martin *et al.*, 2020).

The most commonly used definition of a robot comes from the Robotic Industries Association (RIA) which defines the robot as "*a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed functions for the performance of a variety of tasks*". Its definition is complex and debated because it refers to the different conceptions of work and autonomy. Moreover, this definition does not seem to be adapted to the agricultural context. Lowenberg-DeBoer *et al.* (2020) proposes a definition of a *field crop robot: "a mobile, autonomous, decision-making, mechatronic device that accomplishes crop production tasks (e.g. soil preparation, seeding, transplanting, weeding, pest control and harvesting) under human supervision, but without direct human labour*". The *mobile* character is not compatible with some livestock robots such as Automatic Milking System (AMS). Because this definition is limited to field crops, we proposed a definition of the agricultural robot adapted to the different farming sectors and detailed in our systematic review protocol (Martin *et al.*, 2020): "*An agricultural robot is an re-programmable mechatronic device that performs different farming tasks without direct human intervention and adapted to its environment through data collection and analysis. The agricultural robot is characterized by interactions with the biological and physical environment (plants, soil, animals, etc.). It is composed of a physical artefact made up of one or more sensors (data collection) and actuators (tasks execution) and a software that allows data analysis and then task modulation. The agricultural robot executes tasks (actuators), data (sensors) and services (data analysis).*"

Methods

In order to study the transformations of work after robot adoption in agriculture, we have carried out a systematic review of literature (SRL) considering that literature provides a diversity of results that can be synthesized by the systematic approach (Petticrew and Roberts, 2006). We have previously published a protocol detailing our methodological choices (Martin *et al.*, 2020). Our research strategy is to query two databases: *Web of Science Core Collection* (WoS) and *Scopus*. For this query, we have considered articles, books, book chapters and reviews. We have excluded proceeding papers because they are part of a publication process but do not necessarily represent a finalized scientific work. There are no limits on disciplines, methods and countries. Our query have consisted of our three key concepts - robot, agriculture and work - and associated thesaurus. The first selection process – the screening – has involved an abstract review by two co-authors on this article. We have excluded articles that either do not deal with an agricultural robot as we define it or that do not study the work as we propose to analyse it. The second stage of selection has involved three eligibility criteria:

1. At least one studied technology meets the criteria of our definition of a robot;
2. At least one of the following dimensions of work in agriculture is addressed: farm structure and labour market, work performances, work organization and meaning of work. These four

analytical dimensions are constructed from the analysis of a *test corpus* containing the essential texts on our research question (Martin *et al.*, 2020);

3. The work is studied on at least one of the following scales of analysis: farm system, farmers and/or farm workers in all agricultural sectors (*e.g.* field crops, livestock, horticulture, vine-growing).

The final stage of the selection has consisted in examining all references in the selected corpus. All the relevant references cited - even the proceeding papers- are then submitted to the eligibility criteria. Although the proceedings papers were not selected in the first stage, we include them in this last stage if they are cited in the selected papers and meet the eligibility criteria. After this selection process detailed with the PRISMA flow diagram method (Figure 1), the qualitative analysis covered 60 articles.

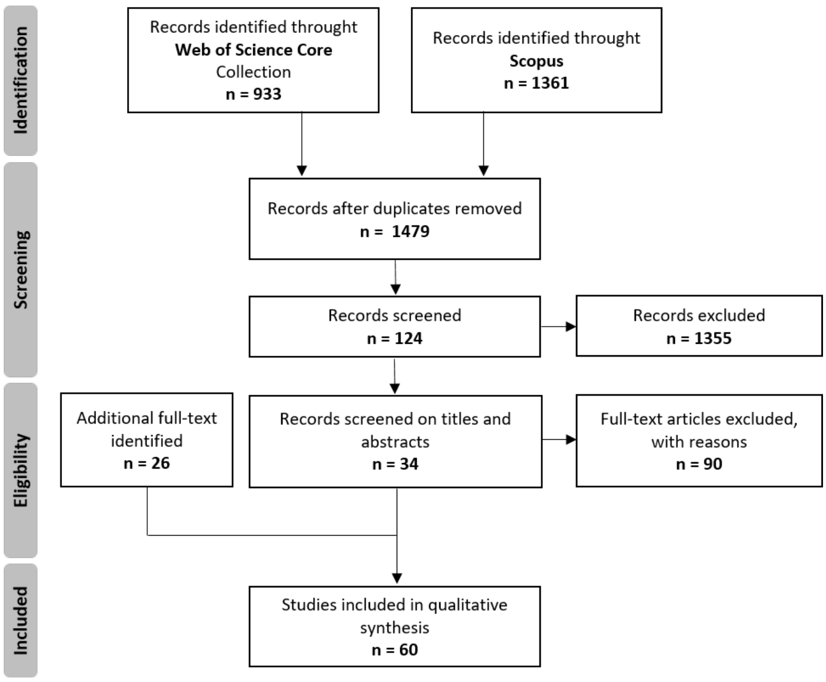

Figure 1. PRISMA flow diagram *(adapted from Moher* et al.*, 2010).*

Results

Description of the corpus

AMS: the first massive robot adoption process

46 out of the 60 selected articles focused exclusively on the AMS or milking robot (Figure 2). This can be explained by the massive deployment of this technology in Europe over the last 30 years: 30% of dairy farms operate AMS in Sweden, 25% in Denmark and 8% in France (Sorel, 2019). The low number of studies for the other agricultural robots is mainly explained by their low deployment. Indeed, the agricultural robotics sector is marked by a gap between the dynamism and communication of economic actors and the poor adoption of these technologies on farms (Caffaro AND Cavallo, 2019; Carolan, 2019). Many challenges remain in order to achieve a higher adoption rate (Wouter Bac *et al.*, 2014).

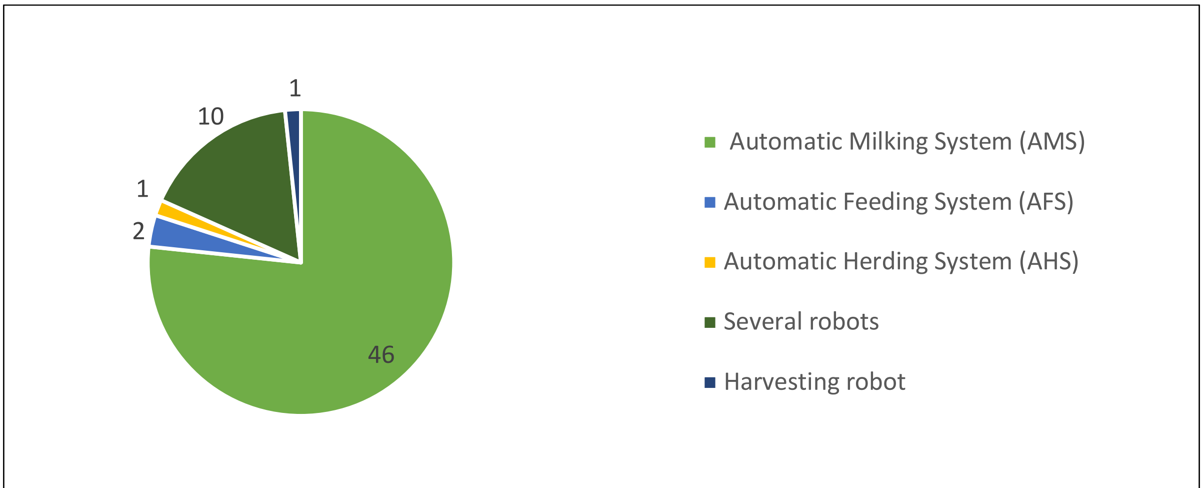

Figure 2: Types of robots analysed in our literature analysis (n = 60); An AHS is a system of slow moving mobile fences controlled by an industrial controller and herds all the cows to the milking robot (Drach et al., *2017).*

Work dimensions covered by the articles selected

Most of the selected articles take into account different dimensions of our analytical framework. The work performances (*e.g.* economic performances, labour productivity) are much more studied than the other dimensions (Table 1). Studies of work performances focus mainly on the milking robot and form one main community around the *Journal of Dairy Science* or conferences related to precision farming or animal sciences.

Work analysis dimension	**Number of reviewed articles covering each dimension** (some are present in several clusters)	**Main concepts and analytical approaches**
Farm structure and labour market	14	- Farm size - Digital divide - Unskilled/skilled labour - Immigration labour
Work organization	15	- Work flexibility - Manual/digital labour - Out of the barn into the office - Data analysing - Workload
Work performances	32	- Profitability - Productivity - Yield, fixed cost and margin - Capital and labour costs
Meaning of work	19	- New rural subjectivities - Co-production of change - Human-animal relationship - Information overload

Table 1. Number of reviewed articles covering each dimension of our analytical framework on work and main concepts related.

Description of the main scientific communities

Three main scientific communities analyse the consequences of robot on farm work. A community uses the frameworks of two main disciplines: Geography of Agricultural Technologies and Science and Technology Studies. It is interested in *co-production of change* related to AMS adoption and with a special interest for human-animal relationship. The main authors identified are L. Holloway, C. Bear and D. Butler (*e.g.* Butler *et al.*, 2012; Holloway *et al.*, 2014a, 2014b; Bear and Holloway, 2015, 2018; Butler and Holloway, 2016; Holloway and Bear, 2017). Another scientific community is mainly interested in economic performance and work organization. It is mainly gathered around the *Journal of Dairy Science* and conferences related to animal sciences (proceeding papers) (*e.g.* Rotz *et al.*, 2003; Speroni *et al.*, 2006; Bijl *et al.*, 2007; Jacobs & Siegford, 2012; Steeneveld *et al.*, 2012; Rodenburg, 2017; Salfer *et al.*, 2017; Tse *et al.*, 2017). A third group takes a political look at all the dimensions of work (Carolan, 2019; Rotz *et al.*, 2019; Vik *et al.*, 2019).

From the beginning of 2010, the number of publications retained in our systematic review has been increasing (
Figure 3), which corresponds to the development of AMS in Northern and Western Europe.

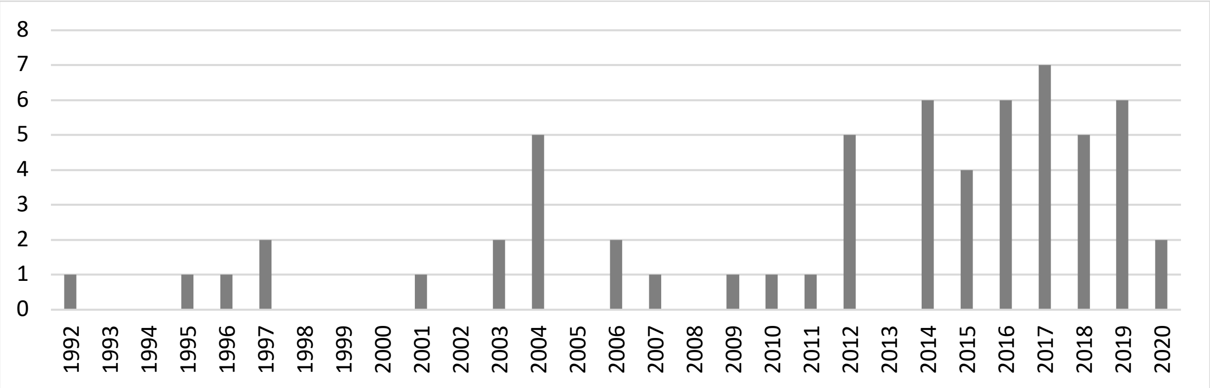

Figure 3. Number of selected articles per year (n = 60) studying work transformations related to agricultural robot.

Qualitative analysis: robot and work transformations on farm

Farm structure and labour market

• Farm structures: robots for large or small farms?

Agricultural robotics has historically been carried by engineers who consider agricultural tasks in an industrial style where *"the machines could work entirely in predefined ways, much like a production line"* (Reddy *et al.*, 2016). According to Reddy *et al.*, this industrial production vision of agricultural work partly explains the many failures to automate agricultural tasks (ibid).

Robots and other automatic devices are often associated with large farming systems (Dusty, 2017). According to Caffaro & Cavallo the lack of capital investment and knowledge explains why small farmers have less access to these tools (Caffaro and Cavallo, 2019). Hence, a large digital divide between big and small farmers appears. Particularly in the dairy sector, several studies have demonstrated that large farms are more inclined to adopt precision technologies (Moyes *et al.*, 2014; Gargiulo *et al.*, 2018). In France, a study in 2001 - which corresponds to the increase of the AMS adoption on farms (Sorel, 2019)

– reveals that farms with AMS are larger (area and herd size) than the national average (Veysset *et al.*, 2001). In addition, these farms are more diversified, leading to labour constraints (ibid).

However, some analysis indicate no significant correlation between farm sizes and AMS adoption (Hogeveen *et al.*, 2004). Even more, Castro *et al.* show a higher satisfaction following AMS adoption for farms with herd sizes below the average (91% versus 58%) suggesting a more adapted technology for small and medium farms (Castro *et al.*, 2015). Moreover, the economic simulation of Salfer *et al.* (2017) showed that AMS was more profitable than parlor systems for 120 cows and 240 cows while the 1500 cow parlor system was more profitable than AMS. Veysset *et al.* clarifie that although farms with AMS have a higher milk production than the national average, the most suitable farms for profitability are family farms with less than 65 dairy cows (Veysset *et al.*, 2001). The dominance of the family farm structure in Western and Northern Europe is one of the drivers explaining that more than 90% of dairy farms using AMS are located in this area (Gallardo and Sauer, 2018). After all, the history of AMS – AMS adoption is mainly in medium and family farms – disputes the studies suggesting that robots are more adopted on large farms.

Relations between farm structure and robot adoption should be considered from another point of view. AMS transforms the technical and economic functioning of the farm and the structure evolves with it. Tse *et al.* relate an increase in the herd size with transition to AMS (Tse *et al.*, 2017). At the dairy sector scale, this increase leads to a structural development in milk production as an unintended consequence of farmers' aggregated investments in AMS (Vik *et al.*, 2019). These authors explain that the increase in Norwegian milk production is the result of the sum of production increases on farms with AMS. At farm level this production increase is part of "*changes to make investments in AMS structurally and economically viable*" *(ibid*).

• Robot and the labour market

The dominance of family dairy farms and the continuous increase in average herd size – accelerated by the end of milk quotas on production (Groeneveld *et al.*, 2016) – are not the only factors that explain the AMS development in Europe (Gallardo and Sauer, 2018). Labour market is a significant driver for robot adoption in general (ibid) and AMS in particular (Schewe & Stuart, 2015). In north-western Europe, agricultural investments are driven by high labour costs and the labour shortage in many developed countries represents a potential for agricultural robotics (Marinoudi *et al.*, 2019; Lowenberg-DeBoer *et al.*, 2020). Marinoudi *et al.* (2019) suggest that the analysis of robots and automation affecting the labour market should be considered at the farm level instead of the macroeconomic perspective generally used for labour market analysis.

Automation also transforms the labour market through the phenomenon of "job polarisation": "*Job polarisation refers to the parallel growth of high-skill (and in principle, high-wage) jobs and low-skill (and in principle, low-wage) jobs at the expense of middle-skill jobs."* (Marinoudi *et al.*, 2019). This *"job polarisation"* can lead to a *"wage polarisation"* which questions the sharing of added value. Rotz *et al.* (2019) also underline the development of a high-skill/low-skill bifurcated labour market. Hence, a disjuncture between skills and labour availability appears in Canada's agri-food industry. AMS represents a relevant example of skill evolutions related to automation at farm level. On one hand, higher education influences interest in AMS (Moyes *et al.*, 2014). On the other hand, the ability to use and read data could be a barrier for many workers (Tse *et al.*, 2018b). Hence, livestock workers need to develop new skills for data analysis and sensors control and may lose caring skills

(Cornou, 2009) which are specific to animal farming and are part of a specific farmer-animal relationship.

Work organization

• Flexibility and quality of life

Dairy farming involves arduous tasks and a rigid work organization marked by twice daily milking duties. The majority of studies share the same main labour motivations and effects with AMS adoption: increased flexibility and reduced workload (Veysset *et al.*, 2001; Jensen, 2004; Mathijs, 2004; Wade *et al.*, 2004; Hansen, 2015; Karttunen *et al.*, 2016). This work evolution contributes to a reduction of physical tasks and improves workers health (Pinzke, 2016; Tse *et al.*, 2018b). The disappearance of milking duties allows a better lifestyle where the time saved is often allocated to family and social life (Mathijs, 2004; Molfino *et al.*, 2014; Tse *et al.*, 2018a). This improvement of the quality of life is also highlighted in the Automatic Feeding Systems (AFS) studies (Da Borso *et al.*, 2017). Hence, robots may allow farmers a "*modern lifestyle*" (Hansen, 2015) and contribute to the attractiveness of dairy farming for younger generations (Karttunen *et al.*, 2016).

Displacement and news tasks

The robot moves and transforms the work in time and space. The AMS releases workers from one of the most important manual task: the milking (Pinzke, 2016). With a conventional milking system (CMS), milking is also a moment for cow observations related to health and welfare considerations and estrus checking (Dijkhuizen *et al.*, 1997 ; Butler *et al.*, 2012). The introduction of the milking robot transfers these tasks to a different time and space. Some studies consider an increase of these herd observation tasks since the cows are not more observed in the milking parlor (Dijkhuizen *et al.*, 1997). The same increase in working time is observed for feeding and cubicle cleaning (Gustafsson, 2004). In addition to the displacement and increase of the duration of some tasks, new tasks appear. The robot machine requires checking for mechanical flaws and proper functioning (Dijkhuizen *et al.*, 1997). The appearance of Management Information System (MIS) in order to follow at least animal performances and even to manage the farm (*e.g.* costs, reproduction, feeding) generates a new activity shifting work out of the barn and into the office (Bear & Holloway, 2018; Lunner-Kolstrup *et al.*, 2018). The office becomes an inevitable workspace and the computer an indispensable interface. This digital monitoring follows the worker via his smartphone and can lead to on-call duties and information overload (Hansen, 2015), blurring boundaries between personal and professional spaces and time. In spite of new tasks and the increase of some tasks, the global reduction of the working time is a major concern for many studies.

Work performances

• Human labour reduction

Milking represents between 25% and 35% of the annual labour demand of dairy farms (de Koning, 2011). The AMS's ability to reduce this labour demand is crucial in a context of farm size growth and labour market constraints. Most studies on AMS suggest a significant reduction in working time between 20% and 50% (Table 2). However, some of these data have to be nuanced because of the methods used, which do not take into account: i) the diversity of production systems and trajectories; ii) the technical and economic farm transformations related to AMS adoption; iii) the evolution of the nature and temporality of work. For example, the management of 24/7 notifications is not measured in these working time studies. Despite these methodological elements, a clear reduction in working time can be found in literature. We highlight that this reduction in measured labour time requirements is disputed by farmers' perceptions. Indeed, many workers claimed that they work longer hours now than before (Butler *et al.*, 2012; Lunner-Kolstrup *et al.*, 2018). The daily milking duties structure the organization of work over time. Milking with CMS generally represents the beginning and the end of a working day for a farmer and represents "a clear and natural 'start' and 'end'". On the contrary, with the AMS there are no specific working hours (Lunner-Kolstrup *et al.*, 2018), farmer's workload is no longer organised around milking (Butler *et al.*, 2012).

Region	Year of publication	Labour reduction	Method	Reference
Canada	2018	20%	Survey over the phone (n = 69)	(Tse *et al.*, 2018b)
N/A	2016	36%	Simulation model	(Shortall *et al.*, 2016)
Denmark	2012	50%	Economic data (n = 18 ; 9 AMS and 9 CMS)	(Oudshoorn *et al.*, 2012)
The Netherlands	2012	no significant difference	Accounting data (AMS = 63; CMS = 337)	(Steeneveld *et al.*, 2012)
The Netherlands	2011	29%	No details (Dutch case–control study)	(de Koning, 2011)
Finland	2010	30%	Accounting data (depends of the year considered : AMS from 59 to 82; CMS16 to 35)	(Heikkila *et al.*, 2010)
The Netherlands	2007	29%	Accounting data (n = 62 ; 31 AMS and 31 CMS)	(Bijl *et al.*, 2007)
West-Europe (Belgium, Denmark, Germany and The Netherlands)	2004	19.8% - 21.3%	Questionnaires (n = 107 famers)	(Mathijs, 2004)
N/A	1996	37.9%	Simulation model (AM-HCT method and farm observation)	(Sonck, 1996)

Table 2. Labour reduction due to Automatic Milking Systems compared with conventional milking systems.

Feeding operations in dairy cow farms represent more than 25% of labour time (Pezzuolo *et al.*, 2016). Automatic Feeding Systems (AFS) is undergoing an important development. Although less studied than the AMS, the AFS allows also a significant reduction in working time. Compared with conventional feeding systems (CFS), the labour dedicated to feeding operations is reduced by 59.2% with the AFS (Da Borso *et al.*, 2017; Pezzuolo *et al.*, 2016).

• Economic performances
According to Caffaro *et al.* (2019) capital costs are a limiting factor for robot purchase for small farms. In the case of AMS, robot, barn construction or modifications and cow purchase amortizations increase the fixed costs (Heikkila *et al.*, 2010; Steeneveld *et al.*, 2012; Ferland *et al.*, 2016). The lower costs is one of the five most important motivations for CMS adoption according to Hogeveen *et al.* (2004). This increase in the cost of capital related to the AMS also impacts the cost of milk production (Heikkila *et al.*, 2010; Jago *et al.*, 2006). However, the diversity of the results concerning margins, returns and

profitability does not allow us to quantify the transformations in economic performances. While some conclude that AMS is more profitable (Salfer *et al.*, 2017; Tse *et al.*, 2018), others argue the opposite (Heikkila *et al.*, 2010; Shortall *et al.*, 2016). While some show an increase in margin and returns with AMS (Heikkila *et al.*, 2010; Ferland *et al.*, 2016), others show no significant difference (Rotz *et al.*, 2003; Oudshoorn *et al.*, 2012). However, the diversity of economic outcomes seems to converge towards a higher cost of capital and a lower cost of labour. Finally, as we have seen above, economic factors are not the first to explain AMS adoption.

Meaning of work

• Mental workload and stress
Although the AMS reduces stress due to the repetitive task of milking as well as physical workload (De Jong & Finnema, 2003; Jensen, 2004; Karttunen *et al.*, 2016), mental workload and stress can occur. This mental stress is explained by four reasons identified in our analysis (Meskens *et al.*, 2001; Karttunen *et al.*, 2016; Hostiou *et al.*, 2017; Lunner-Kolstrup *et al.*, 2018): i) the demanding management of the AMS and complexity of information; ii) the lack of adequate farmer or hired worker skills; iii) the 24/7 standby and the nocturnal alarms; iv) the burden of the debt increases with AMS investment.

• Change in animal-human relationships
With the implementation of the milking robot, breeders spend less time interacting with their animals (Wildridge *et al.*, 2020). This decrease of human-animal interaction renews the relationship between farmers and cows. Cows demonstrate less fear and less stress by human presence. With AMS, this relationship between breeders and cows is also mediated by a machine and the data it provides. The farmer then perceives his animal as a product or a combination of parameters to monitor with consequences on animal welfare (Cornou, 2009). But, according to Porcher & Schmitt (2012), "*the milking robot […] is not per se necessarily a tool that alienates animals and farmers*". Because cows work and are involved in a working relationship with the human (ibid), they "*co-produce change of practices with farmers and robot*" (Bear & Holloway, 2018). This co-production leads to new rural subjectivities (Bear & Holloway, 2015) and redistributes the responsibility between human and non-human entities (Holloway *et al.*, 2014b).

• Robot: towards a new farmer?
In our analysis, changes in farmer's perception and identities are mainly studied through the relationship with cows. Driessen and Heutinck (2014) show changes in what is considered to be a good farmer. But these considerations are only made with regard to the animal relationship. Two studies from the 1990s showed a relation between the self-perception of stockpersons and the attitude regarding towards the milking robot (Seabrook, 1992; Rossing *et al.*, 1997): "*Those stockpersons with a cognised self of being livestock orientated appeared more demeaned by the prospects of automatic milking than those who had a cognised self of being machinery orientated. Similarly, those who perceive themselves as progressive see greater opportunities than those who perceive themselves as traditional*." (Seabrook, 1992). The subjectivity of the worker and sociological aspects are rather considered to explain the diversity of adoption (Schewe & Stuart, 2015) than for the analysis of work transformations resulting from robotization.

Discussion and Conclusion

The robot seems to be a critical factor in the transformation of agricultural work. The profuse studies on AMS provided a relevant example of global work transformation. The generalization of results is complicated because of the specificity of dairy activities and dairy farms (Vatin, 1996), especially in the European context. However, the AMS gives us an opportunity to think about the evolution of work that a robotization of agriculture could result in.

While the robot is often associated with large farms, the deployment of AMS shows a completely different reality. However, structural approaches do not take into account the diversity of strategies, trajectories and forms of social organization of production. Macroscopic approaches are not enough to understand the connection between the labour market and the robotization in the agricultural sector (Marinoudi *et al.*, 2019). While studies showing a spatial heterogeneity in AMS adoption are rare (Hansen, 2015), there is a need to understand the labour market at the territorial level and not only at the macroscopic level.

Changes in work organization are well documented to understand the disappearance, displacement and appearance of new tasks and skills. Few studies focus on collective work organizations. At the farm level, we must understand how the social relationships of production evolve especially the collaboration and power distribution of managerial and family farms. At the territorial scale, how does the robot transform socio-technical groups, local inter-farm cooperation, farm machinery cooperatives and labour-sharing arrangements? Recent decisions regarding the robot in the cheese areas of designations of origin (Courageot, 2018) encourage to study the effects of robotization of work on "*rent* of *territorial quality*" (Mollard *et al.*, 2001).

While economic studies indicate a reduction in working time with AMS, farmers perceive an increase. This difference must question our analytical frameworks and methods. The methods of measuring working time must evolve with digital tools and robots. AMS adoption triggers a profound transformation of the worker's relationship to working time and therefore to work. No study integrates these transformations, *e.g.* measuring the working time associated with managing notifications received on a smartphone during working time and leisure time.

Numerous studies have shown the evolution of work after robotization. However, most of these studies are only interested in AMS. The emergence of new robots should encourage new studies and comparative approaches. Moreover, work is rarely considered in its collective dimension. Thus, research is needed to understand the transformations of robots on the collective organization of work. More specifically, current events (Courageot, 2018) are invited to explore the transformations of collective organizations at the territorial scale such as areas of designations of origin. These transformations of agricultural work raise questions about the evolution and coexistence of agricultural and food models at the territorial scale (Gasselin *et al.*, 2020). Finally, regarding these results and the questions they raise, can we speak of an agricultural revolution (Mazoyer and Roudart, 2002) or a labour revolution (Rifkin, 1995), or even an agricultural revolution through labour?

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