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The Smarterfarmer Project

Farms and the Digital Frontier: Mapping the Digital Landscape of Farming in Denmark

Digitalt Advancement

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Digital Advancement

In the previous chapter, we provided an overview of the use of digital management systems, primary production precision agriculture technologies, and engagement in on-farm data collection across the surveyed farms. Based on this, we categorized farms into digital adopters and non-adopters to explore associations between certain farm characteristics and the tendency to (not) be on the digital track.

In this chapter, we delve deeper into the agriculture digitalization, focusing specifically on digital adopter farms and their level of digital advancement. Digital advancement refers to a farm's ability to adapt to an evolving digital landscape[1]. This encompasses both the current level of technology integration (which we refer to as the "technology dimension") and the extent to which farm digitalization is integrated into the strategic and operational management ("managerial dimension").

We begin by offering insights into the technological dimension of digital advancement across the surveyed farms. This is achieved by examining which farm management tasks are supported by FMIS, which PA technologies are currently in use, and the extent to which FMIS and PA technologies are integrated into farm operations.

Next, we replicate this approach within the managerial dimension by presenting the emphasis that surveyed farms place on digitalization within their overall strategic approach and their perceived ability to effectively work with digital technologies and data. We also examine which farm characteristics are associated with being more advanced across each digital indicator.

[1] Zhang et al., 2019

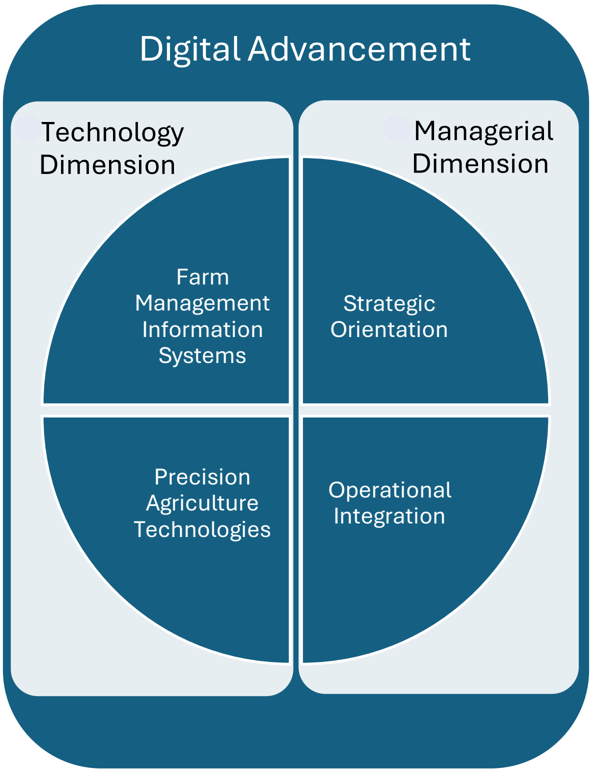

Figure 1: Dimensions of Digital Advancement

The Technology Dimension

In this section, we take a closer look at digital advancement from a technology perspective. We begin by examining how FMIS are integrated among the farms that use them, looking at the range of farm management activities supported by digital systems and the overall breadth of FMIS integration. Next, we extend this analysis to CPA technologies and LSPA technologies used on their respective farms, assessing to what extent specific technologies are utilized as well as overall PA integration.

The use of Digital Farm Management Systems

The purpose of Farm Management Information Systems is to support decision-making and streamline administrative and operational tasks by integrating various types of data to improve efficiency and resilience. What began as simple recordkeeping systems has evolved - and continues to evolve - into more advanced digital tools that vary in their focus, scope, and reliance on farm-specific data[2]. As a result, FMIS adoption looks different from farm to farm; Some use it for just a few tasks, while more digitally advanced farms integrate it into nearly every part of their operations.

Looking at the use of Farm Management Information Systems (FMIS) to support general management activities - those that are not specific to production type - we observe that most digitally supported tasks primarily concern administrative purposes (Figure 2). These include managing the farm's financial situation (74%), tracking and optimizing farming activities (70%), and documenting compliance with regulatory requirements (68%). These activities are categorized as "basic system" functions, as they primarily address traditional farm management needs, without offering support for more specialized tasks[3]. Other, more operational uses for FMIS, such as inventory management (24%), personnel management (25%), or sales and logistics management (28%), are less common. A careful interpretation of this information suggests that, while FMIS systems are widely used for essential administrative tasks at Danish farms, the adoption of more specialized, day-to-day operational tasks remains limited. This may perhaps indicate that there is some potential for further integration of FMIS into more specialized

[2] Fountas et al., 2015

[3] Fountas et al., 2015, p. 45

areas of farm management, which could enhance operational efficiency and decision-making processes in the future.

Figure 2: FMIS uses across general Farm Management Tasks among FMIS-using Farms (n = 1241)

Primarily livestock- and mixed farms reported higher rates of FMIS usage for administrative tasks, particularly for financial management and the recording and optimizing of farm activities, compared to primarily arable farms (Figure 3). At the top of the ladder are pig farms, where over 80% of adopter farms (essentially all pig farms) use FMIS for managing operational finances and processes, followed by cattle farms, with 78% using FMIS for financial management and 70% for process management.

The use of FMIS for tracking and complying with regulations is relatively similar across farm types, indicating that digital systems are commonly employed for compliance-related tasks across all production types. A finer distinction reveals that pig farms lead in this area as well, with 71% of pig farms reporting the use of FMIS for regulatory compliance, while other production types are at around 60%. This suggests that pig farms are particularly advanced in leveraging digital systems for administration and regulatory compliance, setting them apart from other farm types.

When it comes to more operational management activities, such as logistics or inventory management, FMIS usage is noticeably less common among primarily arable farms. In contrast, there seems to be a higher demand for digital support in these areas as livestock specialization increases. Among pig operations, we find the largest share of farms using FMIS to manage personnel (35%), followed by cattle (33%) and poultry (31%). Poultry farms stand out, however, in terms of inventory management (50%) and managing logistics and sales tasks (44%). In comparison, pig and cattle farms are at around 27% and 33%, respectively.

Only around 16-22% of primarily arable farms reported using FMIS for such operational tasks, which is less than their livestock-producing counterparts. The one exception to this trend is in equipment and machinery management, where primarily or partly arable farms report higher usage rates compared to livestock farms. This suggests that, while livestock farms tend to adopt FMIS more extensively for operational tasks, arable farms may have a greater need or place greater emphasis on managing their equipment and machinery through digital systems.

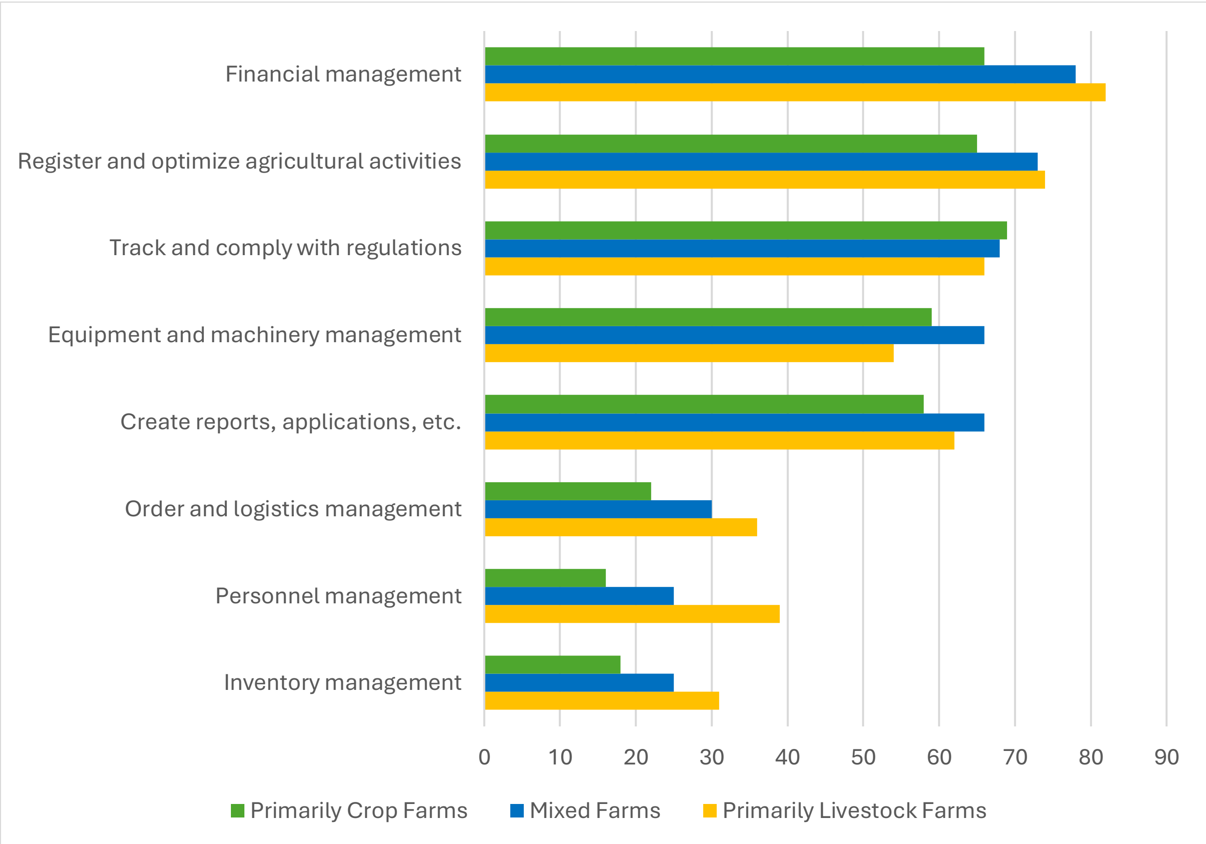

Figure 3: Extent to which General Farm Management Task are supported by FMIS among Adopter Farms

For FMIS-support specific to the farm's main production (Figure 4 & Figure 5), the data shows an interesting distinction between arable- and livestock farms. Primarily livestock farms lead in FMIS adoption for animal and facility management (particularly cattle and pig operations), with 84%

using FMISs for this purpose. In contrast, while still one of the most commonly supported FMIS tasks, less than 70% of primarily crop farms reported using FMIS for field or crop management.

Interestingly, mixed farms show similar usage rates to crop farms for FMIS-supported field and crop management. However, their FMIS adoption for animal and facility management is significantly lower - 20 percentage points less - than that of primarily livestock farms. This suggests that mixed farms are leveraging FMIS for crop management in much the same way as crop farms, but are less integrated in the use of FMIS for livestock management compared to their livestock-dominant counterparts.

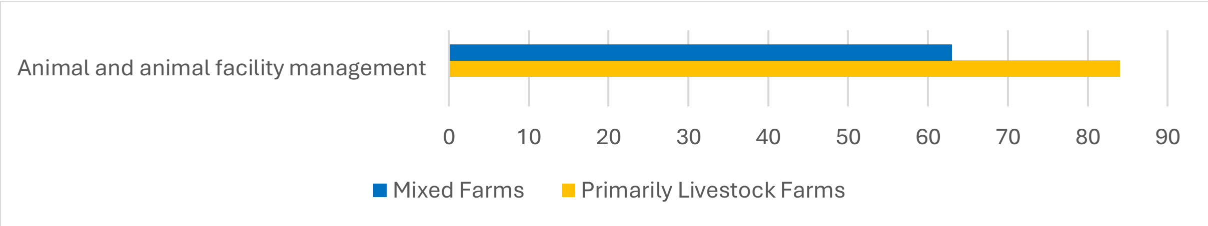

Figure 4: Extent to which livestock-management tasks are supported by FMIS among specialized Adopter Farms

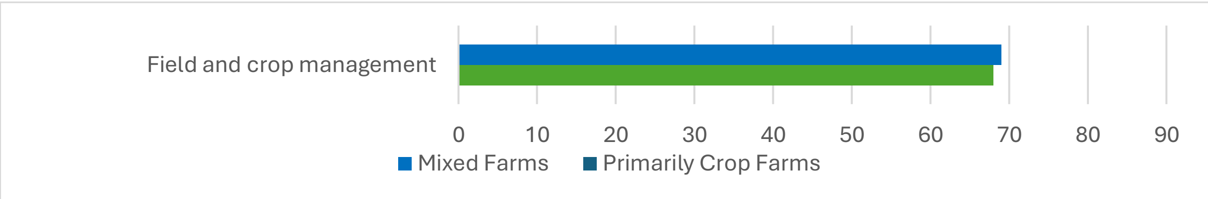

Figure 5: Extent to which crop-management tasks are supported by FMIS among specialized Adopter Farms

Most farms leverage FMIS to assist with multiple aspects of their operations (Figure 6). In fact, the majority of farms rely on FMIS for around 4 to 7 management tasks[4]. This highlights how digital adopters, regardless of farm type, embrace these systems to streamline and optimize a broad range of activities, from daily operations to more strategic decision-making.

This appears to be particularly the case for livestock- and mixed operations, which show stronger FMIS integration: Around half of the FMIS-using livestock and mixed farms report using FMIS across 6-8 farm management tasks, whereas crop farms show a stronger presence in the lower task counts. On average, primarily crop-oriented farms reported using FMIS for an average of 4.8

[4] Notably, around 6% of farms indicated that they use FMIS but did not select any specific management tasks associated with its use. This may reflect either alternative uses of FMIS not covered by the predefined task list, or possible misunderstandings about FMIS use. For clarity and consistency, these responses were excluded from further FMIS-related analysis.

out of 9 possible tasks, primarily livestock-oriented farms used FMIS for about 5.6 out of 9 tasks, and about equally mixed farms reported using FMIS for 6 out of 10 tasks on average.

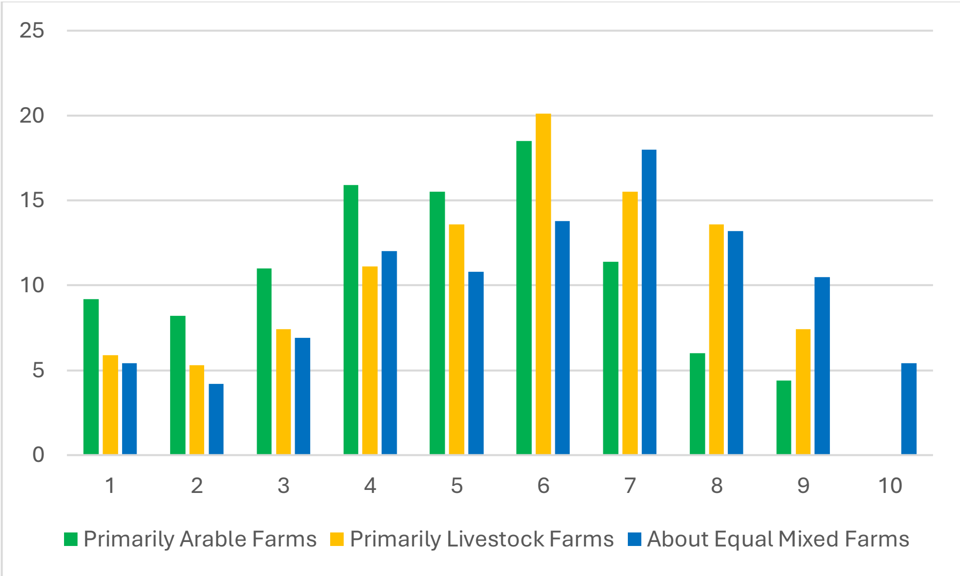

Figure 6: Proportion of Farms Using FMIS for Different Numbers of Management Tasks by Farm Type

To compare the extent to which FMISs are used across farm types, we calculated a relative mean score. This score reflects the proportion of management tasks for which FMIS is used, relative to the total number of options available to each respondent based on their stated production focus. We use this score to explore which farm characteristics are significantly associated with digital advancement in terms of the extent of FMIS integration across different farm management activities. In doing so, we find the following:

- As indicated above, there is a difference between production types in terms of FMIS integration, with farms that have a stronger focus on livestock production generally exhibiting more integration. Specifically, pig and poultry farms tend to have more farm management tasks supported by FMIS. However, when we consider other factors, particularly **economic size**, we find that there is no significant difference in FMIS use based on production focus. Instead, larger farms tend to use FMIS more extensively, suggesting that the size of the farm is a more important factor than the type of production when it comes to adopting and using FMIS.
- Similarly, we find that farms with larger physical size in terms of **cultivated hectares** and **number of animals**, as well as those that have a **larger workforce** and are **operated full-**

time, tend to have more management tasks supported by FMIS. This is unsurprising, as larger farms typically have more complex operations that require more efficient management and coordination across multiple activities. The integration of FMIS allows these farms to streamline their processes, manage larger volumes of data, and optimize resources more effectively. Additionally, full-time operations and a larger workforce likely have the capacity and resources to invest in and fully utilize digital systems.

- The **location** of the farm does not seem to play a role for FMIS utilization, at least when not considering other factors. However, when taking production type and economic size into account, the picture becomes more nuanced. While more livestock-oriented farms report similar levels of FMIS integration across all regions, we find some indications that for primarily arable farms, those located on Zealand tend to be more digitally supported in their farm management, while a larger proportion of primarily arable farms in Southern Denmark show lower levels of FMIS integration. This suggests that regional factors, combined with production type and farm size, may influence the extent to which arable farms adopt and integrate FMISs.
- Similar to what we have seen in Chapter 1, we find a significant association between the **age** of the farmer or farm manager running the farm and FMIS integration, with older farms tending to use less FMIS across different farm management tasks. This could be due to several factors, such as older farmers being less familiar or comfortable with relying on a greater variety of FMIS, while younger farmers may be more open to adopting new systems due to being more familiar with digital technologies and seeing greater benefits in optimizing farm operations through these technologies.
- We find a weak positive association between farms run, or partly run, by female farmers or farm managers and FMIS usage when accounting for size and other farm characteristics. This provides some indication that **gender** may play a significant role in the adoption of digital management systems, possibly due to differences in management styles or priorities.
- We also find some indication that **family status** may play a role. When not considering other factors, there is a positive association between the extent of FMIS use and the number of children of farmers, indicating that farms run by people with more children tend to be more supported by digital management systems. However, when accounting for age, the association becomes insignificant, meaning that the relationship between the number of children and FMIS use is likely confounded by the age of the farmer. In other words, age may be a more significant factor in explaining FMIS adoption, and the initial

positive association with the number of children could be attributed to the age-related factors influencing both family size and FMIS use.

- Moreover, we find a positive association between **education level** and the extent of FMIS use. This suggests that farmers or farm managers with higher levels of education are more likely to adopt and extensively use FMIS technologies. Higher education may provide better access to knowledge, technical skills, and a greater willingness or ability to embrace digital management systems. This highlights the potential role of education in promoting digital adoption and optimizing farm operations through digital technologies.
- Finally, we find no difference in terms of the extent of FMIS use between **organic and non-organic farms**, suggesting that farms, regardless of their production methods, recognize the value of digital farm management support and are similarly inclined to integrate FMIS, likely driven by operational needs and the desire for efficiency, rather than by production method. Similarly, we find no significant associations between the extent of FMIS extent and **legal form of ownership**.

The use of Precision Agriculture Technologies

Precision agriculture refers to a suite of digital technologies designed to manage agricultural production with increased accuracy by capturing and responding to variability within fields and animal conditions[5]. Their primary goal is to optimize inputs and operations based on specific on-site conditions. Similar to FMIS, PA technologies have steadily evolved over the past decades since the commercialization of GPS and improvements in sensing technologies, supporting a wide range of applications and demanding varying levels of user engagement, skills, and learning. As such, PA utilization differs from farm to farm.

As previously mentioned, this report primarily focuses on operation-specific digitalization, emphasizing the use of crop-related precision agriculture (CPA) technology among primarily arable and mixed farms, and livestock-related precision agriculture (LSPA) technology among primarily livestock and mixed farms. To examine the extent of adoption of these technologies among digital adopter farms, we analyzed the share of farms using a specific technology among digital adopters, similar to our previous analysis of FMIS use among adopter farms. We also present usage rates that include non-adopters to provide a clearer picture of the overall adoption rates across farm types.

CPA technology use

When looking at the use of **CPA technologies**[6], we observe that RTK-GPS enabled autosteering stands out as the most widely adopted technology, used by over 65% of respondents and more than 70% of CPA users (Figure 7). This shows that guidance systems are baseline technology in modern farm operations, perhaps because it is relatively easy to integrate and has broad applicability across crops and tasks.

Other more commonly used technologies with over 50% usage rates include section control for pesticide or fertilizer application, which typically may impact cost savings directly and thus help with regulatory compliance. In contrast, crop sensors and autonomous machinery show consistently low usage rates, likely due to their more advanced or specialized application.

Mixed farms show the highest adoption rates across nearly all technologies. Among CPA users, 78% of mixed farms use RTK-GPS, over 66% use section control for pesticide application, and 56.8% utilize prescription maps. Even when including non-users in our regression, adoption rates remain stable — for example, over 52% of all mixed farms use prescription maps, and nearly 72% use RTK-GPS (Figure 8).

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[5] Barnes et al., 2019; Groher et al., 2020

[6] For comparison: https://www.dst.dk/Site/Dst/Udgivelser/nyt/GetPdf.aspx?cid=47210

Notably, and similar to our initial observations in Chapter 1, primarily arable farms show consistently lower adoption rates than mixed production farms despite their stronger focus on crop production. This may suggest that having livestock can enhance a farm's economic stability, thereby supporting greater investment in CPA technologies. The presence of livestock may provide the financial resources and operational flexibility necessary for adopting advanced agricultural technologies like CPA, contributing to higher overall adoption rates on mixed farms.

However, as we will see later, while mixed farms do show higher overall adoption rates than crop farms, this is largely due to the fact that mixed farms tend to be economically larger than primarily crop farms. When accounting for farm size, similarly sized crop farms tend to have more extensive CPA usage than their more livestock-focused peers. This highlights that farm size plays a significant role in the adoption of CPA technologies, with larger farms having more resources to invest in a broader technology setup.

Looking at the primarily-livestock sub-sample, it is interesting to note that, when only considering CPA adopter farms, they show similar usage rates for section control and prescription map technology - and even higher rates for autosteering technology - compared to their more arable-oriented counterparts. However, the usage rate for nitrogen software and remote sensing technologies is lower, which altogether indicates that, while CPA-using livestock farms are adopting some CPA technologies at competitive rates, they are somewhat ‘behind’ in adopting more specialized technologies such as those for optimizing nitrogen usage and utilizing remote sensing for crop monitoring.

Taking the proportion of non-adopters into account, we see a somewhat stronger difference between farm types, with CPA adoption being unsurprisingly more common among the more crop-focused farms (Figure 8). This suggests that, while some livestock farms are adopting specific CPA technologies, crop-focused farms generally have a higher overall adoption rate, likely due to the more direct relevance of CPA technologies to their operations. The gap in adoption rates emphasizes the greater alignment between crop production needs and the capabilities of CPA technologies.

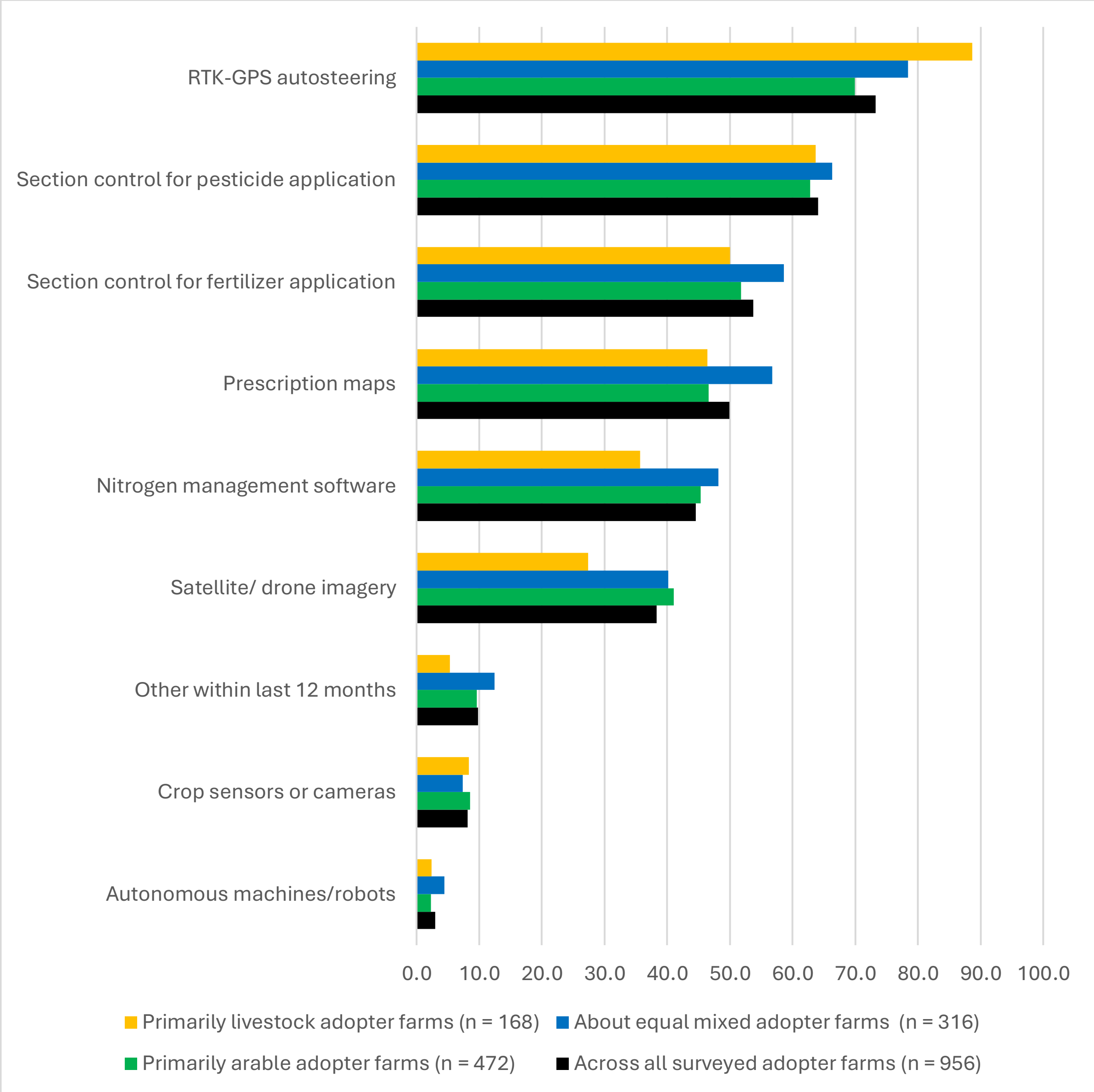

Figure 7: CPA usage rate of Adopter Farms

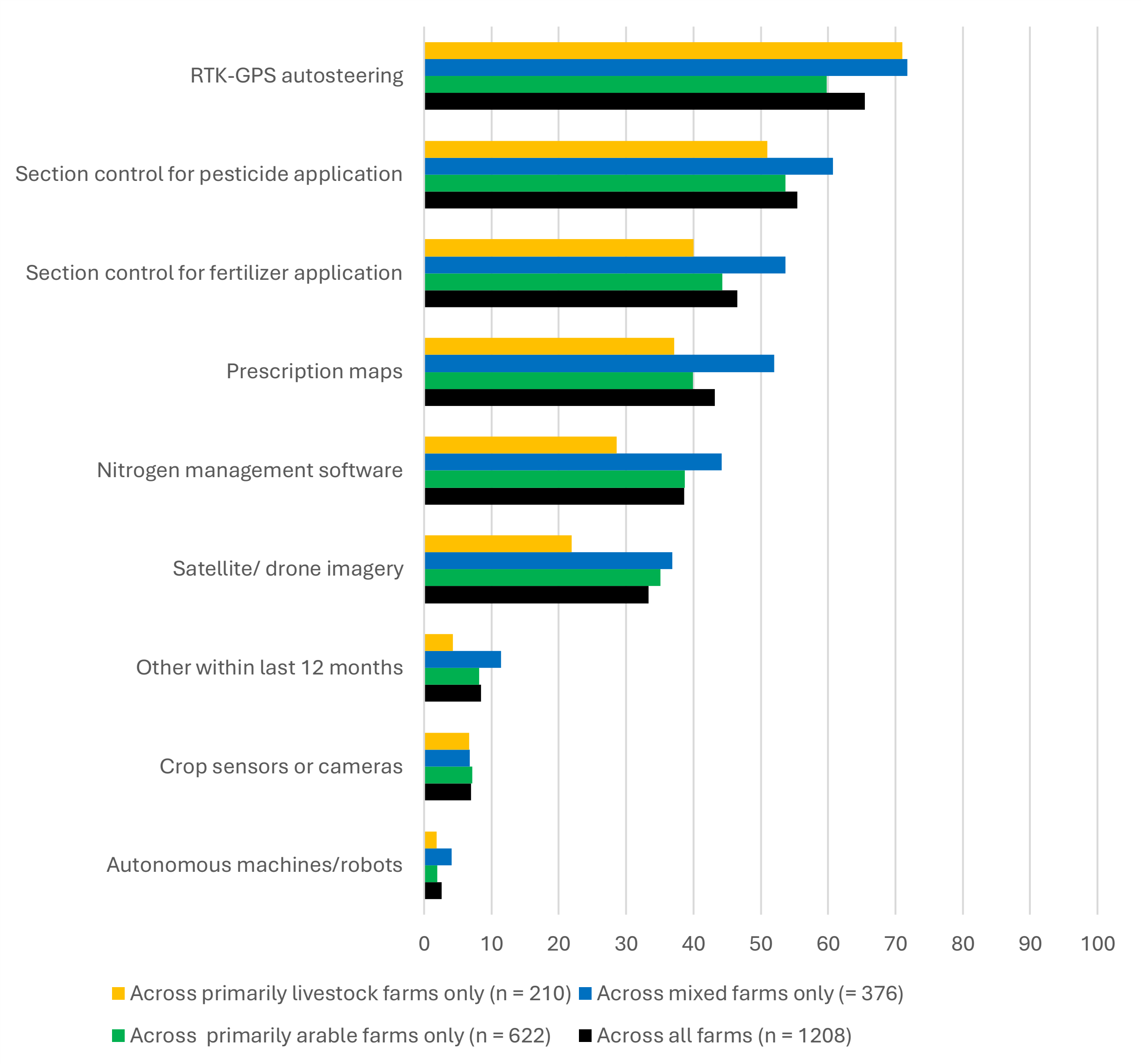

Figure 8: CPA usage rate across Adopter and Non-Adopter Farms

When examining the extent of CPA utilization, we can see that farms with a primarily crop- or mixed production focus are the most advanced in terms of the breadth of technologies in use. (Figure 9). Over a quarter of primarily crop farms and over a third of mixed farms report using six or more different CPA technologies (out of the 8 presented, excluding "other"). On average, CPA-using crop farms utilize 3.8 CPA technologies (2.7 when also considering non-adopters).

Not considering other farm characteristics, this number is slightly higher for mixed farms, with an average of 4 CPA technologies in use among CPA-using farms, and 3.2 when considering both CPA adopters and non-adopters. In contrast, livestock farms that also reported CPA use tend to adopt fewer technologies, with 16% indicating they use six or more CPA technologies and over 40% of these farms reporting usage of only one or two CPA technologies, mostly autosteering.

This likely reflects the fact that CPA is a secondary concern in these operations, with adoption more limited to specific, possibly essential, applications.

Notably, the distribution of the number of CPA technologies in use suggests a divide between adopter farms, with a substantial share of farms using only 1-3 technologies or a wide range (6 or more), while fewer farms fall into the "middle" category. This suggests that some farms adopt CPA technologies more selectively or incrementally, focusing on a few specific tools that meet their immediate needs, while others take a more comprehensive approach, integrating a broad suite of CPA technologies into their operations. This indicates that the adoption pattern is not uniform and may depend on farm size, resource availability, and the perceived benefits of adopting a wider range of technologies. It may also suggest that while some farms are exploring digitalization in a more holistic way, others are adopting technologies more gradually, possibly in response to economic considerations or the perceived complexity of full adoption.

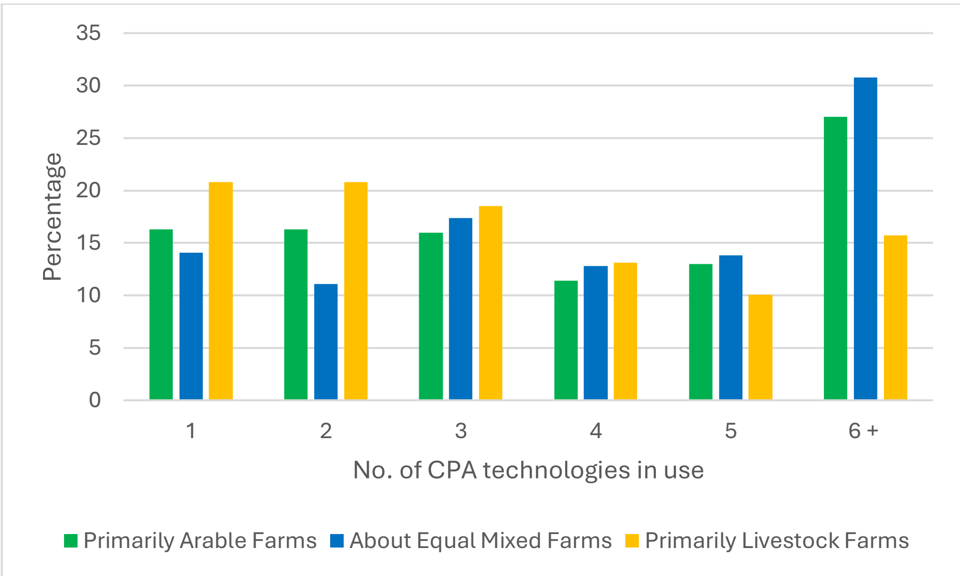

Figure 9: Proportion of Adopter Farms Using a number of CPA technologies by Farm Type (n = 928)

Similar to before with FMIS integration, we calculated a relative mean score to show the extent of CPA technologies in use relative to the total number of presented CPA technologies. Below, we have a closer look at which farms tend to integrate CPA to a higher extent, taking other farm characteristics into account.

- When accounting for farm size among other factors, we find that **primarily arable farms** tend to utilize CPA technologies to a greater extent compared to farms primarily or partly specialized in livestock production. This means that, among similar sized farms, CPA technologies are more widely utilized on farms specialized in crop production to support the precise management of field activities, crop monitoring, and resource optimization. In contrast, livestock farms may perhaps prioritize technologies that are more specialized to their operations, such as animal monitoring or facility management tools, leading to less emphasis on CPA adoption.

- **Farm size** plays an important role overall, with economically and physically larger farms tending to utilize a broader range of CPA technologies. Larger, full-time operated farms often have more resources and capacity to invest in advanced technologies, enabling them to adopt a wider variety of technologies to optimize farm management. This broader adoption of CPA technologies is likely driven by the increased complexity and scale of operations, which require more sophisticated solutions to improve efficiency, manage resources, and enhance productivity. On the other hand, this may indicate that higher levels of CPA adoption, and therefore more digital management and precision, may not be feasible for smaller operations due to the exponential increase in investment and operational costs. Smaller farms may face financial constraints and lack the necessary resources to justify the adoption of multiple CPA technologies, as the costs associated with implementing and maintaining these systems may outweigh the potential benefits. This suggests that while larger farms can absorb the costs of these technologies more easily, smaller farms may need more tailored, cost-effective solutions to integrate digital technologies without overburdening their budgets.
- In terms of **location**, our analysis indicates that farms located on Zealand tend to utilize a wider range of CPA technologies compared to other regions. This could be because the soil conditions on Zealand promote more favorable crop cultivation and a higher concentration of arable farms with the economic capacity to invest in digital tools. Moreover, farms on Zealand may have better access to infrastructure, resources, and support services that facilitate the adoption of advanced technologies. These factors could collectively contribute to a higher level of CPA technology adoption on farms in this region.
- We also find indications that **organic farms** (or those transitioning into organic production) tend to use fewer CPA technologies. This may be because certain technologies, such as section control for pesticide application, are not relevant for organic production, where the use of chemical inputs like pesticides is restricted or avoided. Additionally, organic farms may prioritize different management practices that

focus more on soil health, biodiversity, and natural farming methods, rather than relying heavily on technology. This could result in a lower adoption of precision tools that are more tailored to conventional farming practices.

- Lastly, farm or farm manager **age** is again negatively associated with CPA use extent. This could be due to a variety of factors, such as older farmers being less familiar with new technologies, a preference for traditional farming methods, or a perceived lack of necessity for advanced digital tools in their operations. Younger farmers may be more open to experimenting with and adopting new technologies, seeing them as beneficial for optimizing farm management and improving productivity.

Notably, we find no significant associations between CPA use extent and legal form, family status, workforce size, gender of the farmer or farm manager, and education level of the farmer or farm manager.

LSPA technology use

When looking at **the use of LSPA technologies** among primarily and partly livestock producers, we can see that the usage rates across all technologies are more narrowly spread among adopters compared to CPA technologies (Figure 10Figure 11). Robot technologies for automation - such as systems for milking, feeding, or cleaning - are the most commonly adopted LSPA technologies, used by over 43% of livestock and mixed farms, possibly due to its labor-saving benefits and its established role in livestock operations. Similarly, nearly 40% report using animal sensors and trackers, and over a third make use of facility sensors and cameras.

Notably, while the range of LSPA technologies presented to respondents is narrower - focusing primarily on automation and tracking - compared to the broader variety of CPA technologies, adoption rates for advanced technologies such as automated machinery are significantly higher in livestock farming than in crop production. This could point to a difference in digitalization strategies and -markets, with livestock producers likely to opt for integrated systems and building their operations around those technologies. In contrast, digitalization in crop production appears to be more modular and starts with more basic tools, which are then incrementally extended.

When comparing across farm types, the data indicates that adoption rates of LSPA technologies increase with the degree of livestock specialization. This trend remains consistent even when considering non-adopter farms (Figure 11). For instance, 47.2% of primarily livestock farms report using animal sensors, compared to just 31.4% of mixed farms. This suggests that specialization plays a key role in driving LSPA adoption, with livestock-focused farms more likely to invest in technologies that directly support their core production activities. This trend contrasts with what we observed when looking at CPA utilization, where mixed farms demonstrated higher usage rates.

When taking a closer look at the type of livestock production, we can see that sensors or trackers on animals are the most widely adopted LSPA technologies among cattle farms, with around 81% of LSPA-using farms indicating they use this technology. This is followed by facility sensors or cameras (66%), robot automation technology (56%), and other LSPA technologies (26%).

However, among operations with more animals, such as poultry and pig farms, the utilization of animal sensors and trackers is considerably lower—around 16% for poultry and 32% for pigs. Among LSPA-using pig farms, animal facility sensors and cameras are also less common, with only 15% of adopters stating they use this technology. In contrast, among poultry farms, this technology is more prevalent, with 77% of those surveyed adopter farms using facility sensors and cameras.

Moreover, 17% of pig farms and 19% of poultry farms report using other LSPA technologies. In terms of robot technology for feeding, cleaning, and other tasks, pig and poultry farmers reported similar usage rates to cattle farms, with 53% and 55% adoption rates, respectively.

This shows a clear distinction in the adoption of specific LSPA technologies between different types of livestock farms, with cattle farms leading in animal tracking and sensor technology, while poultry farms demonstrate higher adoption of facility sensors and cameras. Pig farms, on the other hand, show lower overall usage but still adopt certain LSPA technologies such as robots for specific tasks.

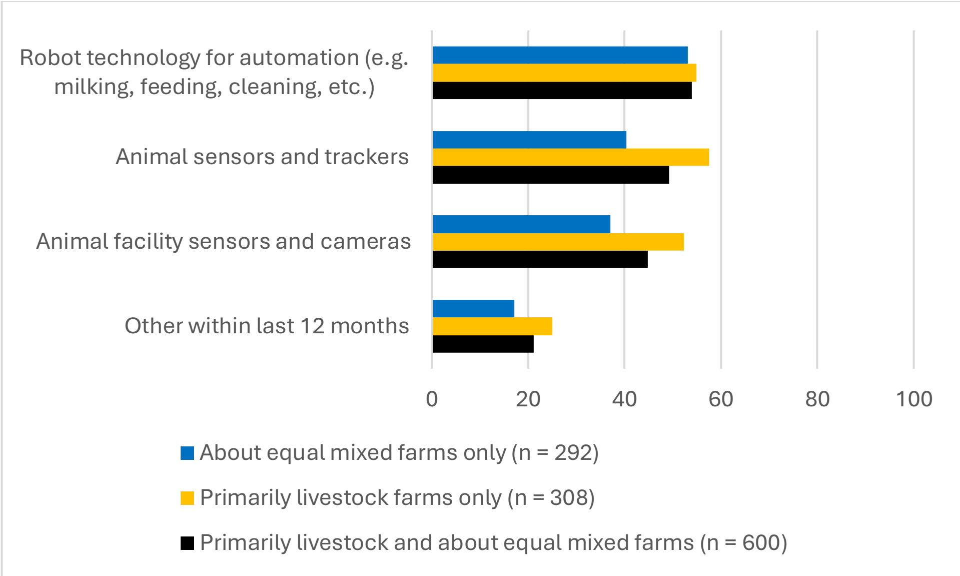

Figure 10: LSPA usage rate of Adopter Farms

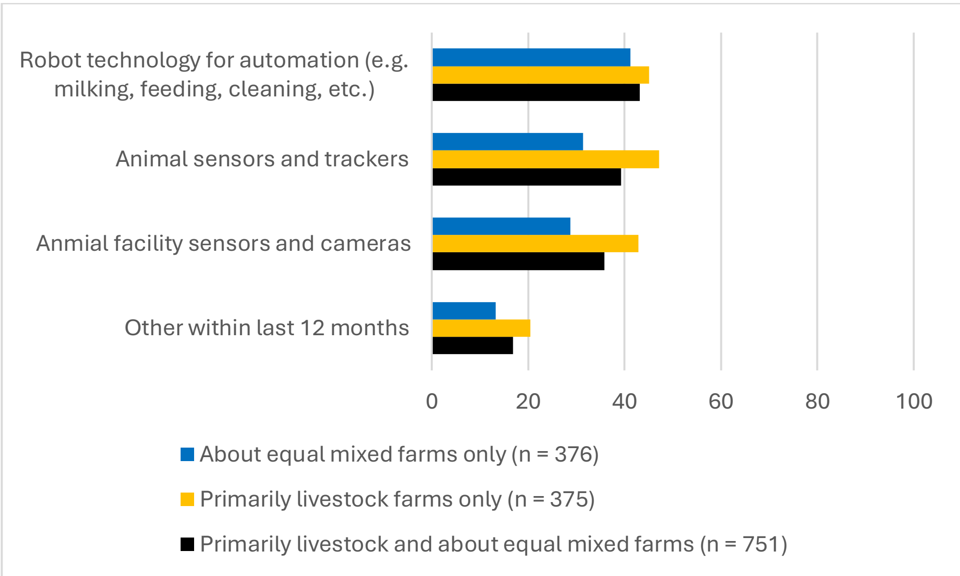

Figure 11: LSPA usage rate across Adopter and Non-Adopter Farms

Among farms that use LSPA technologies, those with a stronger focus on livestock production tend to be more evenly distributed across different levels of use: roughly one-third of livestock farms use one, two, or all three LSPA technologies (Figure 12). In contrast, mixed farms are more concentrated on the lower end, with over 40% using only one technology and fewer progressing to two or more.

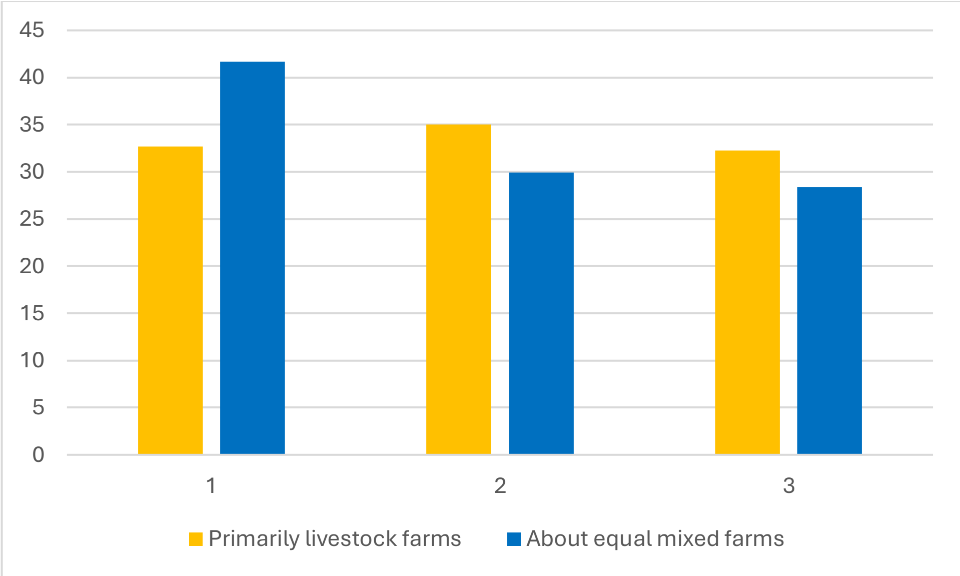

Figure 12: Proportion of Adopter Farms Using a number of LSPA technologies by Farm Type (n = 458)

Again, we calculated a relative mean score to show the extent of LSPA technologies in use relative to the total number of presented LSPA technologies as an indication for digital advancement. Below, we have a closer look at which farms tend to integrate LSPA to a higher extent considering other farm characteristics. We find the following:

- We find no significant difference between primarily- and partly livestock-holding farms. However, we find that cattle farms tend to adopt the listed LSPA technologies to a greater range compared to other livestock-holding operations. This may indicate that cattle farming, with its specific needs for animal tracking, facility management, and automation, benefits more from the inquired technologies. Cattle farms may have operational conditions, such as larger herd sizes or other factors, that make these technologies particularly valuable, especially at the animal level, allowing for better herd management, tracking, and resource optimization.
- For pig or poultry farms, on the other hand, it may not be as feasible to employ technologies with the level of precision that tools like animal trackers or sensors offer, limiting the extent to which these farms adopt the provided technologies. However, when looking at the self-assessed usage intensity of LSPA technologies presented in Chapter 1, we find that pig farms tend to rate their usage extent lower compared to their cattle counterparts (although no significant difference is observed for poultry). Moreover, we do find that some respondents from these groups are still utilizing these technologies as shown before. This suggests that while the adoption may be less widespread or as

extensive as in cattle farming, there are still pockets of adoption in pig and poultry operations that could indicate a growing interest or potential for further integration of LSPA technologies in these sectors.

- As before, farm size and farmer or farm manager age play a significant role in LSPA integration, with smaller farms and farms run by older farmers and farm managers tending to use fewer LSPA technologies. However, the association is less strong compared to FMIS and CPA use, indicating that LSPA technologies, while still influenced by farm size and age, might have a broader appeal or be perceived as more accessible – or economically necessary - across farms of different sizes and farm managers of varying ages.
- In contrast to what we observed in terms of CPA use extent, we find indications that organic farms are more likely to adopt a wider range of LSPA technologies. This could indicate that organic farms, with their focus on sustainability and efficient resource management, may see greater value in adopting technologies that enhance animal welfare and improve operational efficiency. Additionally, organic farms may be more open to adopting innovative technologies, such as automated monitoring systems and tracking tools, that can provide valuable data to support the documentation of animal welfare practices and sustainable farming methods, thus enhancing the farm's ability to meet regulatory requirements and appeal to consumers who value these principles.

Regarding other farm or farmer characteristics, such as location, legal form, gender, or education level, we find no conclusive evidence of a significant impact on the extent of LSPA use.

Primary-operation PA technology use

Lastly, to compare digital advancement across farms with different production focuses, we created a final relative means score. This score measures the extent to which a farm uses PA technologies that are relevant to its specific production type (e.g., crop, livestock, or mixed). In other words, rather than comparing farms based on the exact same technologies, this score reflects the extent to which each farm integrates PA technologies that are directly applicable to its main operations.

We call this metric Primary-Operation PA (PPA) usage. This approach allows us to compare digital adoption across different types of farms by focusing on how well each farm utilizes technologies that are specifically suited to its core activities. By doing so, we get a clearer picture of digital advancement across diverse farming systems, taking into account the unique needs and challenges of each type of production.

Comparing farms based on the extent to which they adopt PA technologies for their primary operation, we find the following associations:

- **Negative association between PPA usage and age**: Older farmers or farm managers tend to adopt fewer PA technologies for their primary operation, suggesting once again that age might be a factor in the willingness or ability to integrate new digital tools into farm management.
- **Positive association between PPA usage and economic size**: Larger farms, in terms of production output, are more likely to adopt PA technologies. This suggests that farms with greater economic resources have the capacity to invest in and implement these technologies more extensively.
- **Positive association between full-time status and PPA usage**: Farms run on a full-time basis in terms of registered working hours tend to adopt more PA technologies. Full-time operations may have more time, resources, and commitment to integrating digital technologies into their daily operations compared to part-time farms.
- **Positive association between cattle farms and PPA usage**: Cattle farms are more likely to adopt PA technologies compared to other production types. This is perhaps likely due to the specific needs of managing larger herds, optimizing feed, tracking animals, and improving facility management.

The Managerial Dimension

With regard to their strategic orientation towards agriculture digitalization (Figure 13) and their operational digital capabilities (Figure 14), the majority of surveyed adopter farms[7] reported a strong managerial focus on farm digitalization.

Strategic level

In terms of strategy, about 70% of respondents recognize the value of digital technologies in improving farm operations, and most farms aim to strengthen their digital competencies (72%) and have a good understanding of relevant technologies (64%). This indicates a high level of awareness and commitment to building the knowledge needed for long-term digital integration. However, over one-third of respondents acknowledged a gap in their understanding of available technologies, suggesting opportunities for further education and training.

Notably, in terms of short-term strategic focus, fewer farmers seem as confident. Only around half of adopters or aspiring adopter farms reported having a clear plan for using digital technologies and actively experimenting with them. This indicates that, while there is strong recognition and commitment to the value of digital technologies in improving farm operations in the long term, there is still a gap or uncertainties in terms of immediate, actionable strategies.

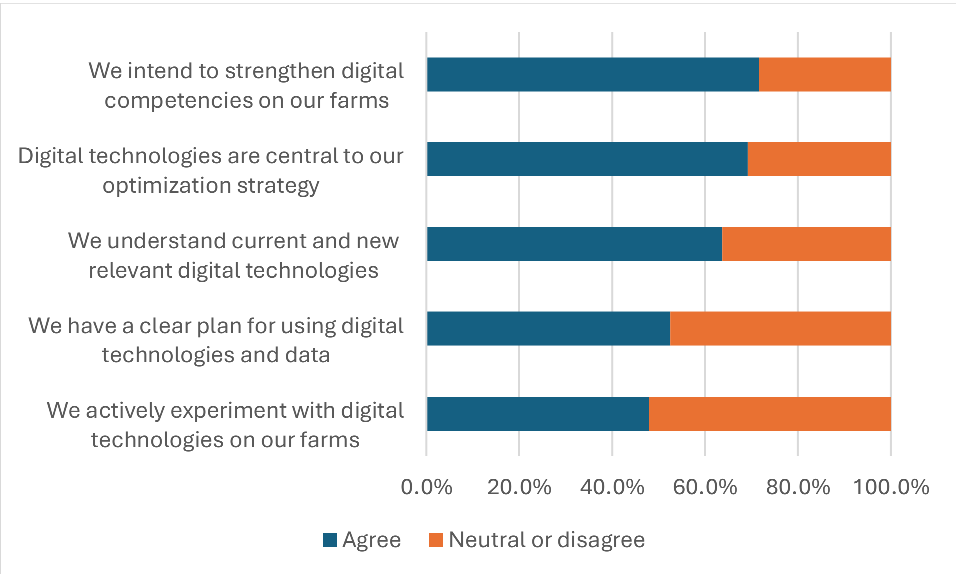

Figure 13: Strategic orientation assessment (n = 1275)

[7] We only asked respondents who stated that they currently use, or in the case of their strategic orientation, plan to use, digital technologies, questions about strategic and operational digital advancement. Respondents who indicated that they do not use, and do not plan to use, digital technologies have been excluded from this part of the survey.

We scored each farm on their strategic orientation toward digitalization based on their responses to the questions above to analyze which farm and farmer characteristics are associated with being more advanced from a strategy perspective. When taking other farm characteristics into account, we find the following associations:

- **Location:** There is a positive association between farms on Zealand and strategic orientation toward digitalization, particularly in contrast to Central Jutland and Southern Denmark, all other factors being equal. This indicates that farms located on Zealand are more likely to prioritize digitalization in their strategies.
- **Economic Size:** There is a positive association between economic size and strategic digital orientation. This suggests that larger farms, in terms of production output or revenue, are more likely to have a stronger strategic focus on digitalization. Larger farms may have more financial resources to invest in digital technologies and systems, as well as more complex operations, making digitalization a more viable strategy.
- **Workforce Size:** There is a positive association between the average size of the workforce on a farm and strategic digital orientation. This indicates that farms with larger workforces may have more capacity to implement and manage digital technologies, facilitating their adoption and integration into farm management practices.
- **Full-Time Operation:** There is a positive association between full-time operated farms and strategic digital orientation. This suggests that farms run full-time are more likely to engage in long-term digital strategies, possibly because they have more dedicated resources and time to invest in digital technologies compared to part-time farms.
- **Farm Type:** There is a positive association between primarily arable farms and strategic orientation toward digitalization, particularly compared to primarily livestock farms with otherwise similar characteristics. This indicates that arable farms may currently have a stronger focus on integrating digital technologies to optimize their operations. Perhaps this points to differences in the maturity of agriculture digitalization between these two operation types, with technologies for livestock farming being more integrated and mature. As a result, livestock farms may require less strategic thought to navigate the digitalization landscape, as digital capabilities on these farms are already quite advanced, given the large proportion of users of automation technologies (see above). In contrast, the market for crop-related technologies may be more fragmented, and arable farms may face more challenges in identifying and integrating suitable digital technologies. Consequently, there is a greater need to develop digital capabilities on arable farms, driving a more focused strategic orientation toward digitalization.

- **Gender:** There is a positive association between farms fully- or partly run by female farmers or farm managers and strategic orientation toward digitalization. This suggests that, all other factors being equal, female farm managers may be more inclined to pursue digitalization strategies, particularly in the area of farm management systems. As we observed earlier, farms run by female farmers and farm managers also tend to use more digital systems to manage farm tasks, indicating a stronger focus on leveraging digital systems and strategically incorporating to carry out management activities.
- **Age:** There is a negative association between age and strategic orientation toward digitalization. This indicates that farms run by older farmers or farm managers are less likely to prioritize or engage with digital strategies, potentially due to comfort with traditional farming methods, limited technical knowledge, or reluctance to adopt new technologies.

We find no clear pattern with regard to organic status, legal form, family status, or education level of the farmer or farm manager. These factors do not appear to have a significant impact on the strategic orientation toward digitalization.

Apart from structural factors, we found a strong positive association between farms that reported to a higher degree that digital systems used by suppliers, service providers, or customers lead them to invest in digital technologies, and their strategic orientation toward digitalization. This could indicate that farms are more likely to prioritize and strategize around digitalization when external stakeholders, such as suppliers or customers, drive the adoption of digital systems. This suggests that the influence of **the broader agricultural ecosystem plays a significant role** in shaping a farm's approach to adopting and integrating digital technologies into their operations.

Operational level

Turning now to the respondents' assessment of their farm's digital advancement in terms of operational digital capabilities, we see that respondents are generally confident, particularly with regard to handling data (Figure 14).

Over 80% of data-incorporating farms stated that the data they have is useful for decision-making, and 75% reported frequently assessing how they use data to improve operations. This reflects a very high rate of satisfaction with the quality of the collected data and a strong commitment to continually improve their data usage to enhance operations. Moreover, 68% stated that they are good at incorporating data into decision-making, indicating a solid level of confidence in their ability to effectively integrate data.

However, the discrepancy between perceived data quality and the ability to incorporate that data may indicate that some farms are not fully leveraging the data they collect in their decision-making processes. In particular, integrating data from different sources may be a challenge, as only 56% of respondents agreed that they integrate data from various sources when making decisions. This suggests that while integration is occurring, there may be opportunities to increase the systematic application of data integration across the sector.

Additionally, 68% of farms agree that they or their partners have systems in place to keep data secure. However, the remaining neutral or negative responses indicate that some farms may not have clear security measures in place or are unsure or indifferent about the protection of their data.

Regarding the operation of digital technologies, just over 50% of the digital adopter farms stated that they are good at operating their digital technologies. However, most respondents (75%) expressed confidence in their ability to locate expert assistance on digital technologies, reflecting Denmark's robust network within the agricultural sector.

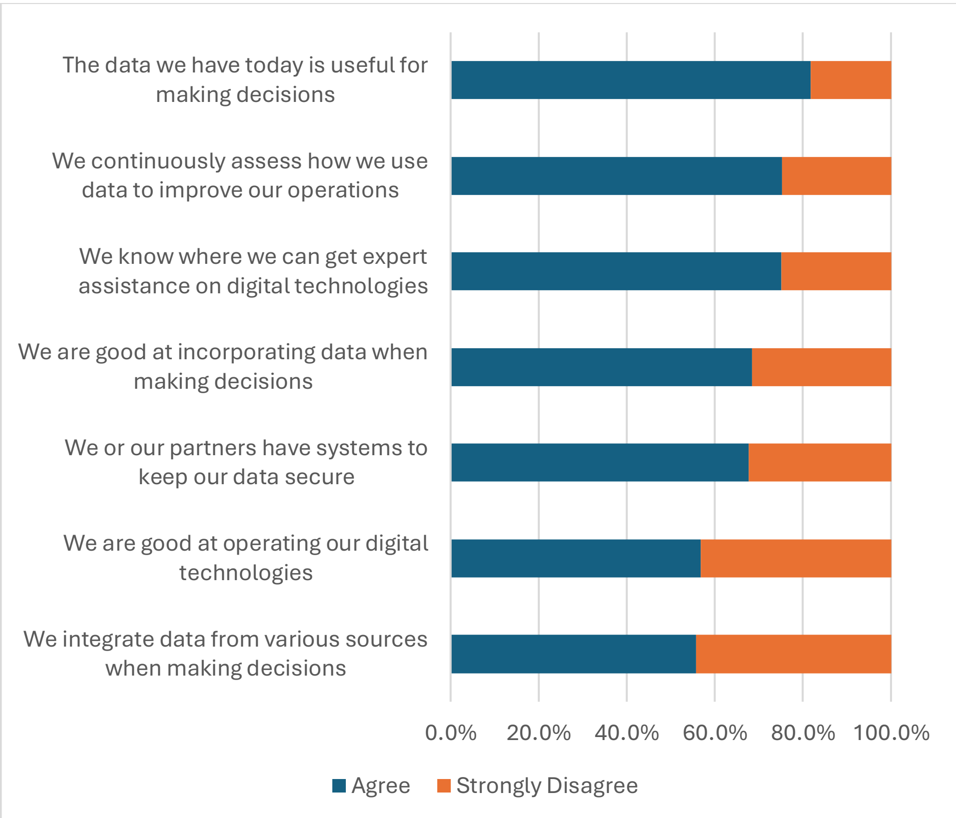

Figure 14: Operational assessment overview

As with the strategy, we scored each farm on their strategic orientation toward digitalization based on their responses to the associated questions. When taking other farm characteristics into account, we find the following associations:

- **Economic Size:** There is a positive association between economic size and the respondents' digital advancement assessments on an operational level. This means that larger farms, in terms of production output or revenue, tend to perceive themselves as more advanced in their operational use of digital technologies. Larger farms may have more capacity to integrate digital technologies into their daily operations, likely resulting in higher perceived digital capabilities.
- **Age:** There is a negative association between the age of the farmer or farm manager and the digital operational score. This means that older farmers or farm managers tend to rate their operational use of digital technologies lower compared to their younger counterparts, again indicating less familiarity with or reluctance to adopt newer digital technologies among older farmers, or a stronger preference for more traditional methods.

Otherwise, we find no significant structural associations, meaning that there is likely no significant difference across farms in terms of who runs them, where they are located, or what production method they use, in how well they perceive their digital capabilities. While we do have some weak indications that farms with a larger workforce, farms run by female farmers or farm managers, and farms run by married (vs. unmarried) farmers rate themselves higher, these associations are not strong enough to make conclusive statements. These factors may have a marginal impact, but they are not significantly driving the perception of digital capabilities across the surveyed farms.

As with the strategy-level assessment, we find that farms that stated that external parties encouraged their engagement with digitalization have a strong tendency to rate their data- and technology-operational capabilities higher, all other factors equal. This supports the interpretation that agricultural digitalization and farms' digital advancement are boosted by a strong, integrated supply chain and support network, something Denmark’s agricultural ecosystem perhaps may be particularly good at. This suggests that the interconnectedness of stakeholders, such as suppliers, service providers, and customers, plays a crucial role in driving digital advancement, enabling farms to more readily integrate digital technologies into their operations and improving overall digital capabilities across the sector.