Operational efficiency and regulatory barriers influencing agricultural drone adoption

by

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ABSTRACT

Although American agricultural producers have opportunities to improve their productivity and decrease costs using drones, the adoption rates remain relatively low due to regulatory constraints and knowledge-based barriers. To gain an understanding of both the motivators for its adoption and the barriers to its widespread adoption, a survey was administered that gathered data from 50 producers, which included details on both the types of farms they operated and their utilization. Participants represented a generationally diverse pool, including Baby Boomers (born 1946–1964), Generation X (born 1965–1980), Millennials, also referred to as Generation Y (born 1981–1996), and Generation Z (born 1997–2012). They each completed a questionnaire that assessed the efficiencies gained in drone use and the primary factors driving their adoption (cost savings and reduction in inputs) as well as the barriers they experienced (technical expertise, regulations, and time). A chi-square statistical analysis resulted in a statistically significant ($p < 0.001$) relationship between the generational group of respondents and their farming experience. In describing their drone-related operational efficiencies, respondents used the same terminology (e.g., cost, spraying, training, and monitoring), indicating that producers prioritize operational efficiencies over maximizing revenue. In addition to the chi-square analysis, a personal diary analyzing the regulatory pathway to receive a university-based Federal Aviation Administration (FAA) Part 137 exemption detailed the costs and duration (22 months) incurred through the compliance process, which provides evidence that regulatory compliance costs are prohibitive to its adoption. The outcomes of this research will provide valuable information to extension educators developing curriculum, regulators working to

reform agricultural aviation regulations, and drone technology manufacturers seeking market-appropriate solutions for American agriculture.

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CHAPTER I: INTRODUCTION

While American farmers have exhausted all other opportunities and are facing continually increasing pressures due to rising input costs, labor shortages, and varying climate conditions, technological innovations in agriculture have become increasingly urgent due to an estimated global population of 9.7 billion by 2050 (United Nations 2019). Consequently, drones have emerged as key players in the digitalization of American agriculture.

For more than two decades, precision agriculture has been implemented by U.S. farmers and adheres to the adoption pattern established within Everett Rogers' seminal work, Diffusion of Innovations. Rogers (2003) based the five adoption groups (i.e., innovators, early adopters, early majority, late majority, and laggards) on the risk tolerance, need for information, and influence of social network properties on agricultural producers. Rogers identifies five characteristics that drive the diffusion of innovations: perceived relative advantage of innovation (speed/precision), compatibility of innovation with existing business practices, regulatory complexity and challenges in data interpretation complicating the adoption of an innovation, trialability of innovation, and observability of an innovation. As the number of attributes associated with drones increases, each has its own unique associated issues. The relative advantage perceived to exist with it is substantial, particularly in the improvement of speed and precision; however, the complexity of obtaining the data and complying with regulatory requirements will slow the adoption process.

Use of aerial imagery as a management tool in U.S. row crop production is limited. Research from the USDA's (United States Department of Agriculture) Economic Research

Service (McFadden, Njuki, and Griffin 2023) estimates that the number of acres where aerially managed systems exist in row crop production are approximately 7% of the total planted corn, 9.8% of the total planted soybeans, 3.5% of planted winter wheat, 2.8% of planted cotton, and 4.6% of planted sorghum. The adoption of aerial management systems by U.S. agricultural producers provides indirect evidence of the level of drone adoption in row-crop production. In contrast, adoption of autosteering (i.e., automated guidance) systems by U.S. agricultural producers exceeds 50% of all planted acres for most crops, signifying a vast discrepancy between established and emerging forms of precision agriculture. These differences lead to a subsequent conclusion that the agricultural sector is still in the early stages of Rogers' adoption framework for drone technology.

Based on research, data-intensive technologies, such as drones and yield monitors, are adopted more slowly than highly automated systems like guidance or section control. For instance, Nicholas J. Miller et al. (2019) found out that technologies in precision agriculture that make use of data, for instance, yield monitors and drones, were usually adopted at a slower pace compared to others such as guidance systems and section control. The findings in this regard offer support to the claim that the challenges posed by data management can serve as a deterrent in adopting new technologies despite their advantages.

In Australia, Zuo et. al. (2022) examined the patterns of adoption associated with drones among irrigated agricultural producers; Michels et al. (2020) examined the adoption of producers in Germany; and Skevas and Kalaitzandonakes (2020) analyzed patterns of mixed-farm operations in Missouri to determine drone adoption factors. In addition, the Chinese market has experienced extremely rapid growth in drones since 2020. Notably, DJI

Agriculture's (2025) estimated that over 400,000 of its agricultural platforms were in active use worldwide by the end of 2024. The variability in its adoption factors discussed by these studies illustrates that many factors impact adoption, namely, technological performance, legal relations, type of agricultural enterprise, and the availability of service providers.

Networks of supporting infrastructure, such as dealers and consultants, are another factor that can influence adoption rates since it can be difficult for producers to adopt technologies especially those that are complex and require high levels of integration. It is in this regard that the issue of network externalities is introduced. According to Michael L. Katz and Carl Shapiro (1985), network externalities occur when the value of technology is positively impacted by the number of users and networks that emerge around it. In agriculture, Thomas W. Griffin et al. (2022) posits that adoption of new technologies is limited by the lack of adequate services.

Utilizing survey data collected directly from agricultural producers, this paper presents results of drone adoption from a financial and operational use perspective, analyzing the following: operational efficiencies, cost savings, primary motivation factors for adopting them, and experienced barriers to implementation. By providing data that establishes how survey respondents perceive its usage, the outcomes of this paper enhance the growing body of knowledge on how producers evaluate drones as an operational technology.

CHAPTER II: LITERATURE REVIEW

2.1 Theoretical Framework: Rogers' Diffusion of Innovations

The theoretical framework for this study is built upon Diffusion of Innovations (DOI); it is grounded in rural sociology that used stakeholder analysis, measuring the adoption of hybrid corn seed in Iowa farm communities during the 1940s and early 1950s (Rogers 1962). The data strongly suggest an S-shaped distribution curve across the five groups identified by Rogers based on their risk-taking capability, the amount of information needed before deciding, and the social behaviors that influence their determination as to whether to invest in a particular technology. Five innovation characteristics are used to evaluate the degree to which an innovation will be adopted, including but not limited to 1) relative advantage, 2) compatibility, 3) complexity, 4) trialability, and 5) observability.

Depending on the perspective used to determine drone innovation characteristics, both McFadden et al. (2023) and Rogers (2003) found enough research evidence to support that one or more of these five characteristics account for 49% to 87% of individual adopters' decisions regarding whether to adopt them. As previously stated, each of the five characteristics is present within the context of drone usage; namely, relative advantage is determined by how much time can be saved by using them; compatibility relates to whether the use of aerial imagery will complement existing farm management processes; complexity refers to regulatory requirements and the need for some manufacturers to obtain FAA (Federal Aviation Administration) certification to operate; trialability relates to the opportunity to use it on a small scale before full use; and observability relates to the ability of nearby producers to observe the benefits of using them.

2.2 Precision Agriculture and Drone Adoption in the United States

Numerous forms of precision agricultural technologies have been adopted by producers in the U.S. over the last 20 years, and the USDA (through the Agricultural Resource Management Survey, ARMS) has continuously tracked and monitored the adoption of precision agricultural technologies on a national scale since the mid-1990s. Currently, the most extensive assessment of precision agricultural technologies available is presented in the report "An Assessment of the Adoption of Precision Agricultural Technologies" (McFadden, Njuki, and Griffin 2023). In this report, the findings generally indicate that over 50% of the producers of large-row alternative crops (corn, wheat, and cotton) report having variable-rate application (VRA), soil mapping, and yield mapping technologies present in their operations, while fewer than 25% of respondents on smaller farms report having any form of precision agricultural technology present. The lack of precision agricultural technology adoption by smaller farms compared to larger farms can be associated with the principles of economies of scale, in that most small farms have fixed costs spread over a larger revenue-generating operation.

Additionally, with reference to drone adoption specifically, there is a strong correlation between the lack of use of aerial imagery in farm management practices. Research indicated that most producers who are utilizing precision agricultural technologies have not only publicly available datasets but also a technical consultant supporting their decision-making process, which would indicate a more substantial digital engagement than those still assessing whether to utilize them. This difference may be explained by the nature of encoding in particular technologies. According to Nicholas J. Miller et al. (2019), technologies that involve interpreting extensive information about data, such as drones and yield monitoring devices, place an especially high cognitive burden and a certain level of technical expertise requirements on users. On the other hand, more automated technologies, for example, guidance systems, may fit better into production routines. It might help explain the rate of growth between precision agriculture technologies.

Schimmelpfennig's (2016) findings illustrate that the economic and operational gains achieved from utilizing yield maps or soil maps in the production of corn (consequently resulting in more net income of 1.8% than for farms that did not use precision agricultural technologies) provide empirical support for the economic rationale behind adopting precision agricultural technologies. However, the next regression analysis necessary to produce reliable economic forecasts relative to drones is further confused because incomes from their operations require a greater investment in both hardware and software, versus similar producers using only auto-steering and a drone involved in agriculture.

2.3 Generational Differences in Technology Adoption

While technological variables affect acceptance levels, demographic characteristics of agricultural producers also play a major role in determining acceptance rates. As indicated by Griffin, Traywick, and Yeager's (2022) and Ofori, Griffin and Yeager (2020) studies of the demographics of Kansas agricultural operators, 50% of producers in Kansas fall within the Baby Boomer generation (born 1946–1964), while the Silent Generation represents about 20% of farmland ownership in the state. The next generation of producers includes Generation X (born 1965–1980) and Millennials, also referred to as Generation Y (born 1981–1996), who have more familiarity with general technology through their experiences thus far, but may not have sufficient funds available for independent investment.

Finally, Generation Z (born 1997–2012) represents the youngest cohort entering agricultural operations. Another important finding related to the adoption of new technologies was that multi-generational producers are likely to adopt new technologies more quickly than single-generational producers; thus, technology diffusion may occur via multigenerational cooperation. Generational characteristics clearly support this study by having the four generations of producers compared regarding their motivations for technology acceptance and their perceived barriers to acceptance. At the same time, generation-related differences may not be purely due to perceptions toward technology. In many cases, the experience accumulated through time may affect how farmers weigh risk, costs, and potential benefits. Thus, it may prove that the generational divide is driven by the disparity in prior exposure to technological innovations.

2.4 Barriers to Drone Adoption: Regulatory, Financial, Human

Barriers to acceptance of precision agriculture, according to literature on this topic, focus on cost barriers, the complexity of the technology, regulations, and knowledge gaps related to the technology. Another overlooked problem may be the lack of a support network behind the technology in question. Without adequate service infrastructure, producers may encounter difficulties as there will be no local support or maintenance resources available should any issues occur. This assumption corresponds with the idea of network externalities (Katz & Shapiro, 1985) that suggests that technology's success will depend on its acceptance and support network. In agriculture, as suggested by Griffin et al. (2022), restricted access to the network makes technology usage seem riskier. Popp, Griffin, and Pendergrass's (2002) research used a cooperative survey method to assess producer perceptions and realities of using precision agriculture. Overall, producers tended to overestimate their costs and underestimate the benefits of implementing precision agriculture based on the timing difference between the expenditure of new investments in precision equipment and anticipated returns. Unknown future returns from current-day investments in drone technology continue to be estimated based only upon the cost of the investment, which is known and well-defined immediately.

The barrier to connectivity identified in research by Whitacre, Mark, and Griffin (2014) indicates that although 100% of urban residents have access to at least one wired broadband service provider, only about 78% of rural residents have access. This percentage is likely to be lower in the very remote areas of agricultural production. Drone -generated information, such as high-resolution imagery and Normalized Difference Vegetation Index (NDVI) imagery, will require broadband bandwidth capacity for data transfer through the data communications process from generation to processing to integration with farm management software (FAA 2020). If there is no reliable broadband access, the ability to generate any useful information derived from a drone will be reduced. Along with technological and economic barriers, regulations may constitute a new barrier to the use of innovations. Differing from financial expenses, which can be planned, the regulatory process is often unpredictable and uncertain. Increased uncertainty may deter producers who seek technology that can be rapidly adopted in the seasonal cycle.

CHAPTER III: RESEARCH QUESTIONS AND HYPOTHESES

The articles identified above provided this research study with a theoretical and practical framework for documenting three topics described in the following way:

RQ1: What were the primary reasons producers chose to adopt versus not adopt drones, and did that vary by generational group (Baby Boomers (1946–1964), Generation X (1965–1980), Millennials/Generation Y (1981–1996), and Generation Z (1997–2012))?

- **H1:** There is a statistically significant relationship between generational group and the primary reasons for adopting or not adopting drone technology, with younger generations more likely to adopt due to perceived technological benefits and older generations more influenced by cost and risk concerns.

RQ2: How did producers view the profitability and return on investment from drones in comparison to other options available in agricultural production?

- H2: Producers generally perceive drone technology as having uncertain or delayed profitability compared to other agricultural technologies, regardless of generational group or farm size.

RQ3: What barriers to acceptance of drones existed, and did specific groups experience higher levels of barriers compared to other groups?

- **H3:** There are significant differences in perceived barriers to drone adoption across generational groups, with older producers more likely to report regulatory and technical barriers compared to younger producers.

CHAPTER IV: DATA AND METHODOLOGY

4.1 Survey Development and Implementation

The survey instrument for this research was developed based on a structured questionnaire to collect quantitative data and qualitative information from producers related to their use of precision agriculture. This current study's survey methodology was an online survey of agricultural producers, conducted over six months from September 2025 until February 2026. The survey was distributed using an open URL link that allowed voluntary participation. The link was shared through social media platforms, including Twitter/X and LinkedIn, and it was also posted to online agricultural discussion forums such as NewAgTalk. The LinkedIn post generated approximately 145 impressions and 67 link clicks during the data collection period, and 50 people responded. Before full deployment, the survey instrument was pilot tested with colleagues to evaluate clarity and functionality. A total of 6 individuals responded to the pilot version, and minor revisions were made before the final survey was released.

One of the most important innovations in the study, as compared to the previous studies, is the generational structure of the survey instrument. That is, each respondent completed a different set of questions instead of all respondents completing the same set of questions; thus, based on the year of birth of the respondent, the researcher created a generation-specific question path. All respondents were asked the first question, which was when they were born. Once that information was completed by all respondents, additional demographic-related questions specific to each respondent's year of birth were then administered to each respondent accordingly by generation. The second category of questions administered to the respondent within each generation included geographic location, farm size, type of agricultural production, years of farming experience, and generation-specific perceptions related to drones.

For example, Baby Boomer respondents were presented with many financial-related questions related to drone technology adoption compared to other technologies, such as global navigation satellite systems (GNSS), including Global Positioning System (GPS) -based guidance and autosteer technologies. Generation X respondents were presented with questions related to perceived financial value from technology-based on aerial data for profitable decision-making, reduced reliance on labor, and payback period analysis. Millennial respondents received questions related to initial sources of interest in drone technology, methods to collect data using this technology, comparisons of investment to other agricultural technologies, and participation in agricultural technology networks. Finally, Generation Z respondents were presented with questions related to the complexities, creative uses, how they researched drones, perceptions regarding cost-related barriers, and collaborating with other younger producers.

The unique design of the survey allows researchers to collect age-appropriate variations of generational influences; however, direct statistical comparisons cannot be made among the four generations on the generation-specific questions. Statistical comparisons among the four generations apply to demographic questions common across the four generations.

4.2 Sample Characteristics and Survey Results

The sample consisted of 50 respondents (all who provided a year of birth), and generational comparisons could be made across all respondents, but not all respondents completed all detailed demographic questions related to farm size, geographic distribution, and agricultural production types; therefore, generational differences in demographics are supported by each generation completing a different question set. All 50 producers provided their number of years of farming experience as indicated in the appropriate generation's question modules.

4.3 Analytical Techniques

The analytical methodology employed a combination of descriptive statistics, cross-tabulations, inferential statistical tests, and qualitative text analysis. In addition to descriptive statistics and cross-tabulation analysis, the feasibility of estimating a binary response model was considered. A logistic regression model was explored in which drone adoption (adopt / not adopt) served as the dependent variable, and farm size, generational group, and years of farming experience were evaluated as explanatory variables. Because of the limited sample size, the regression results were evaluated cautiously and were used primarily for exploratory analysis. Descriptive statistics were used to summarize producer demographics, motivations for acceptance, technology operational advantages, and perceived barriers to acceptance. Chi-square tests of independence were used as a statistical test to examine the relationship between generational groupings and producers with and without a minimum of 20 years of farming experience. The multi-generational respondents were compared using the non-parametric Mann-Whitney U test to evaluate differences in years of farming experience coded as greater than 20 years versus less than or equal to 20 years. The Mann-Whitney U test was selected instead of a t-test because the distribution of farming experience was not normally distributed and sample sizes within groups were unequal, making a non-parametric test more appropriate. Statistical significance was established at $\alpha = .05$ for all statistical tests performed.

In addition to statistical tests, operational performance was contextualized using a standard working rate equation commonly applied in agricultural engineering. The formula is expressed as:

$$Working\ Rate\ \left(\frac{acres}{hr}\right) = \frac{mph\ x\ width\ x\ field\ efficiency}{8.25}$$

where:

- mph = average ground speed of the drone in miles per hour.
- width = effective swath width of the application (in feet).
- field efficiency = proportion of theoretical capacity achieved in practice, accounting for turning, refilling, and other operational delays (expressed as a decimal or percentage).
- 8.25 = conversion constant derived from 5280 feet per mile ÷ 640 acres per square mile.

For analytical purposes, the equation can be rearranged to estimate field efficiency from manufacturer specifications:

$$Field\ efficiency = \frac{Working\ Rte\ \left(\frac{acres}{hr}\right) x\ 8.25}{mph\ x\ width}$$

This formulation allows back-calculation of implied field efficiency values using operational data. For this study, DJI Agras T50 specifications were used as a benchmark (DJI, 2025).

A qualitative content analysis of producers' qualitative responses in the open-ended text box on the survey was conducted using the standard approach most used in applied agricultural economics research (Griffin, 2026; Griffin & Gammon, 2020) by combining, cleaning, and counting the words contained in the free-text qualitative responses, each of which will provide a word frequency count.

CHAPTER V: RESULTS

5.1 Respondent Demographics

The total number of respondents involved in the survey amounted to 50 individuals. The largest portion of those respondents was Generation X (n=15), followed by an almost even representation of two other groups: Millennials and Generation Z (n=12). The smallest generation within the respondent sample included Baby Boomers (n=11). As for the agricultural characteristics of the population under analysis, it was diverse. Specifically, there were various types of operations that were represented in the respondent sample. Crop production (n=20) prevailed over any other operations. Then came mixed operations (n=19), specialized crop operations (n=7), and operations related to animal farming (n=4). Therefore, most respondents engaged in crop farming, either alone or combined with another type. Although every respondent provided the necessary demographic data, not everyone answered the question on detailed demographics including the size of the farm, its geographical location, and production type. That is why one should approach such data cautiously since it cannot present the whole sample.

Table 5.1: Respondent Demographic and Farm Characteristics

Demographics	Category	Count	Frequency %
Generation	Boomer	11	22.0%
	Gen X	15	30.0%
	Millennial	12	24.0%
	Gen Z	12	24.0%
Farm Size	Under 50 acres	4	8.0%
	50 to 200 acres	8	16.0%
	201 to 500 acres	8	16.0%
	501 to 1,000 acres	11	22.0%
	Over 1,000 acres	19	38.0%
Farm Type	Crop production	20	40.0%
	Specialty crops	7	14.0%
	Mixed	19	38.0%
	Livestock	4	8.0%

Table 5.2: Descriptive Statistics for Continuous Variables

Variable	N	Mean	Std. Dev.	Min	Max
Years farming	50	15.90	9.30	0.50	25.00
Birth year	50	1979.36	18.92	1955.00	2004.50
Age	50	45.22	17.79	21	70.00
Farm size (acres)	50	813.50	588.96	25.00	1500

Note: *Continuous variables were estimated using midpoint values for categorical ranges.*

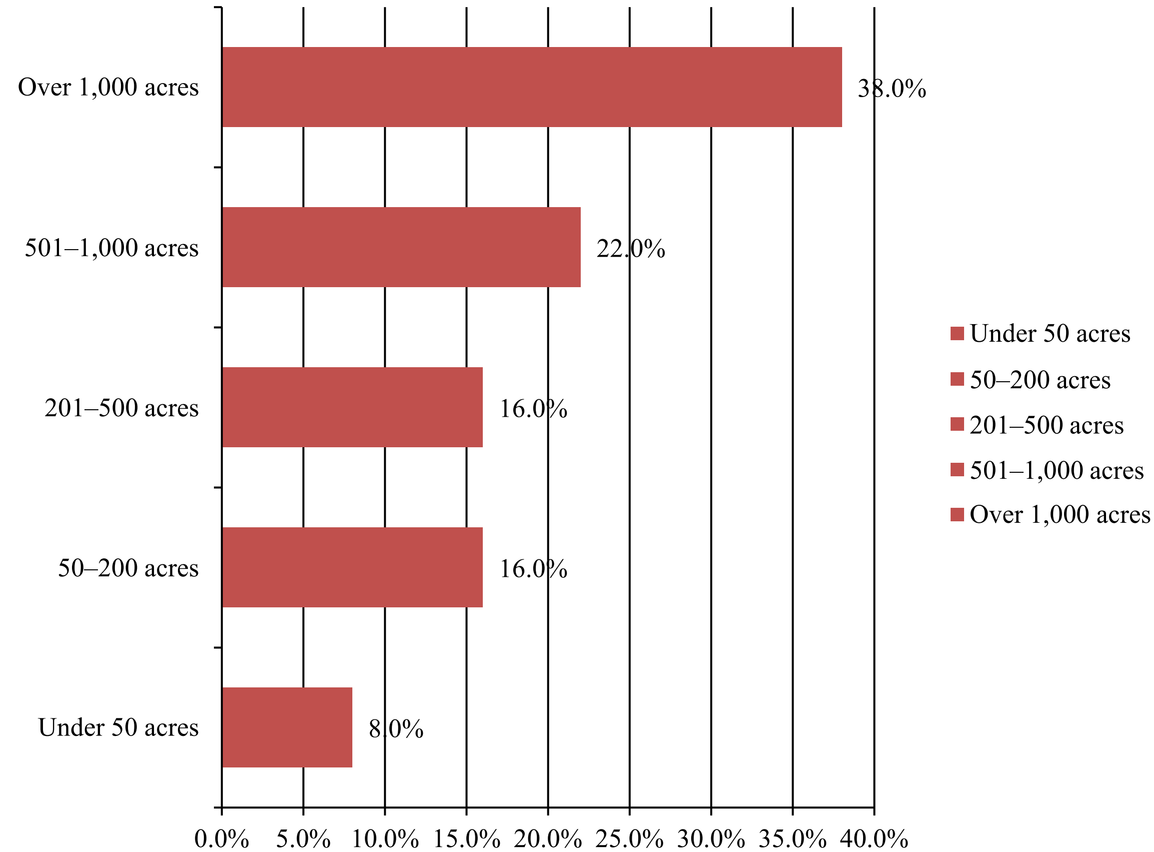
Below is a map indicating locations of respondents from USA. The locations for respondents outside USA are not included in the map.

Figure 5.1: Geographic Distribution of Survey Respondents within USA

5.2 Farm Size Distribution

The difference between farms' sizes was considerable, yet relatively large companies prevailed. Specifically, it was farms over 1,000 acres in size (n=19). The second highest proportion was comprised of respondents owning farms of 501-1,000 acres in size (n=11). Hence, most farms had at least 500 acres. There were eight farms of 201-500 acres and 50-200 acres. Finally, there were four relatively small farms having less than 50 acres. Most farms belonged to the category of larger companies that could afford to implement new innovations. Such a tendency was observed in a similar study. Namely, farm size was identified as a determinant of the use of technology in agriculture. More specifically, larger farms tend to apply precision technology more actively as the investment is easier to justify.

Figure 5.2: Distribution of Survey Respondents by Farm Size (n = 50)



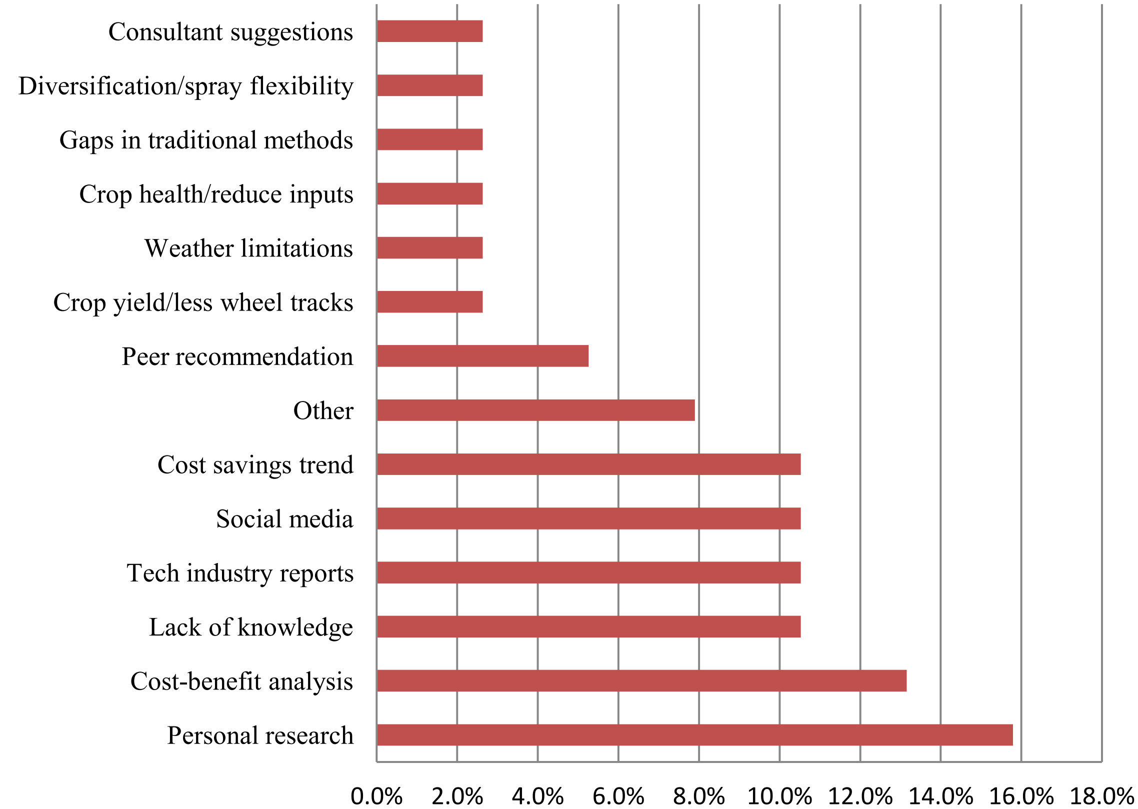
5.3 Generational Experience

There is a significant generational difference in years of farming experience across all 50 respondents to the survey. Respondents were grouped into older and younger categories using the 1980 birth year cutoff, which corresponds to the boundary between Generation X (born 1965–1980) and Millennials/Generation Y (born 1981–1996). Respondents born in 1980 or earlier were classified as the older group, and those born after 1980 were classified as the younger group. This grouping was used to allow statistical comparison because of small sample sizes within individual generations. For respondents 50 years and older (Baby Boomers and Generation X respondents), many of the group (73%) reported that they have been farming for greater than 20 years. Conversely, only 8% of respondents who are 49 years and younger (Generation Y and Generation Z respondents) reported a comparable length of farming experience. The results of a chi-square statistical analysis indicated that these two groups (younger vs. older) exhibit statistically significant differences in farming experience ($x^2 = 21.47$, $p < 0.001$). Similarly, the results of a Mann-Whitney U statistical test comparing experience-coded years between these two groups demonstrated a statistically significant difference ($U = 531.5$, $p < 0.001$). Specifically, older respondents averaged 20.9 years of farming experience compared to younger respondents, who averaged 9.0 years of farming experience; the difference demonstrates that older producers have more total experience and will have increased familiarity with older or legacy equipment while also having a baseline to evaluate new technology.

5.4 Adoption Motivations

Regarding the factors that contribute to adoption, responses suggest that adoption decisions are driven by both practical and personal factors. Personal research was the most mentioned motivation among respondents regarding their decision to implement drones, alongside cost-benefit analysis. It seems that, perhaps, many producers make decisions regarding drones based on their own assessment rather than marketing or pressuring factors. Trends, including cost savings and industry publication exposure, were mentioned as some factors influencing people's views. A small group also mentioned peer influence and social media mentions; however, the extent of such responses differed among the participants. Overall, adoption decisions appear to be relatively personalized, considering prospective gain against unique characteristics. Cost aspects and industry trends seem to have played a considerably more important role among generation X respondents than others. Still, even among this group, the motivations differ, suggesting that adoption is determined by a variety of factors rather than a single motive.

Figure 5.3: Motivations to Adopt Drone Technology (n = 38)



Note: Some questions were not applicable to baby boomers

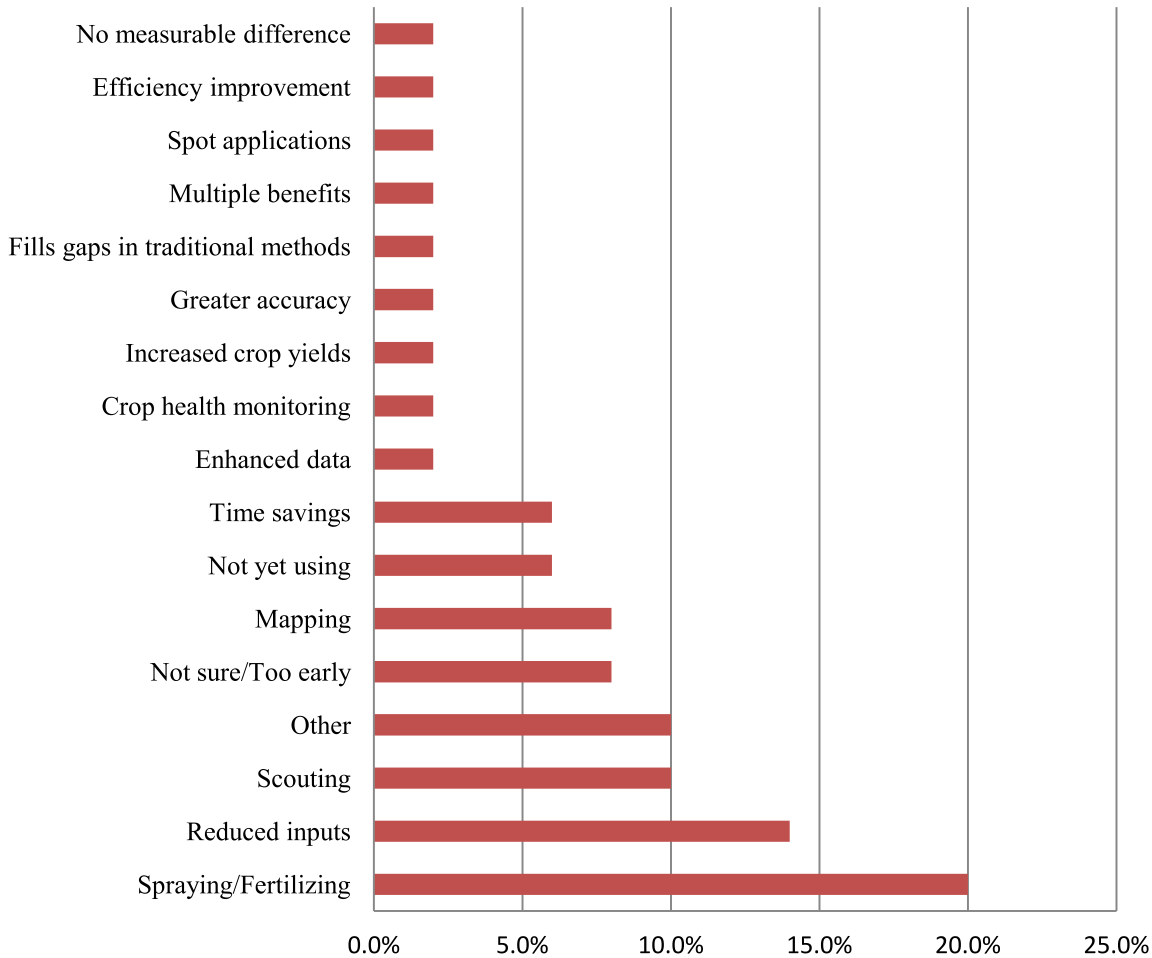
5.5 Operational Benefits

As for the main benefits from using drone technology, respondents mostly pointed to practical advantages instead of strategic ones. One of the most common reasons for adopting drone technology was better spraying and precision application (n = 10). This reflects the common use of drones in routine farming activities.

Other commonly reported advantages included reduced costs of inputs (n = 7) and increased speed (n = 4). Respondents also mentioned developments regarding monitoring and mapping capabilities of drones, allowing for better field vision. Finally, some suggested that it was too soon to evaluate the technology fully, meaning that benefits had not been identified. Several responses implied that the usefulness of drones was linked to their ability to operate locations rather than whole fields. Recognizing problematic spots and then using drones to apply inputs only where needed can help reduce unnecessary expenditure and possibly increase efficiency. Still, the size of these benefits depends on how well the technology will fit existing practices.

To provide a benchmark for operational performance, manufacturer specifications for the DJI Agras T50 were used to back-calculate field efficiency using Equation (2). Based on an operating speed of 10 m/s (22.37 mph), an effective swath width of 8 m (26.25 ft), and a reported working rate of 50 acres/hr, the implied field efficiency is approximately 70%. This benchmark offers a technical reference point for interpreting producer-reported operational benefits, highlighting how manufacturer data can contextualize perceptions of precision, input savings, and speed (DJI, 2025).

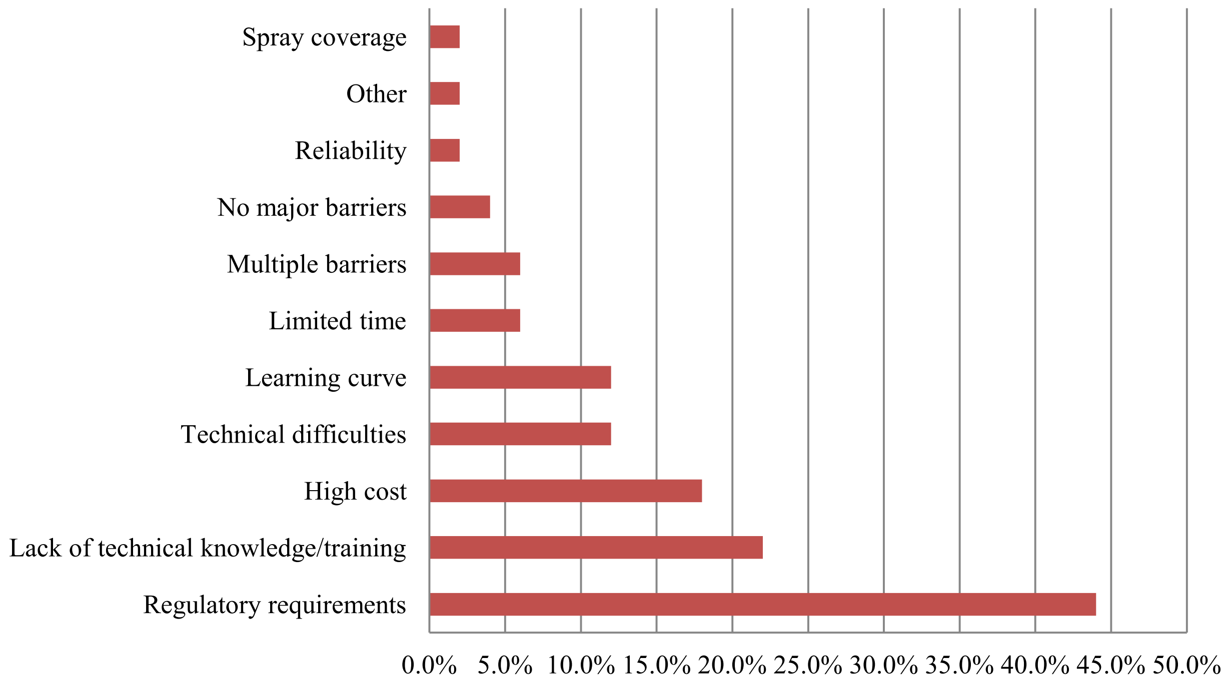
Figure 5.4: Operational Benefits of Drone Use (n = 50)



5.6 Obstacles to Adoption

Survey respondents frequently mentioned challenges to adopting technology. Regulation and licensing concerns were the most frequently cited hindrance (n = 23). These responses indicate that, at least for many producers, the issue of getting permission to use drones may be as important as the technology itself. Training needs and lack of technical knowledge were also mentioned as challenges (n = 11). Large initial investments (n = 8) and technological problems (n = 6) were mentioned less often than regulatory challenges. Finally, a few respondents mentioned time constraints or indicated that they did not face any difficulties. Overall, the comments highlight that adoption depends on multiple factors rather than single ones. Even when benefits are recognized, the time, effort, and uncertainty involved in training and meeting regulations may seem to be a barrier to adoption. This could explain why technology is slow to adopt.

Figure 5.5: Obstacles to Drone Adoption (n = 50)



5.7 Perceived Profitability and Return on Investment

Most respondents (53%, n = 15) reported that they are evaluating the perceived profitability of drones relative to other agricultural technologies (e.g., irrigation upgrades and automation). None of the respondents indicated that they believe they will be less profitable than other technologies currently in use.

5.8 Statistical Test Result

Table 5.3: Summary of Statistical Tests

Test	Variables	Statistic	p-value	Interpretation
Chi-square	Gen. group × Experience (>20 yr vs. ≤20 yr)	$\chi^2 = 21.47$	< 0.001*	Significant association
Mann-Whitney U	Older vs. younger × Experience (coded years)	U = 531.5	< 0.001*	Significant difference

*Note: * indicates significance at α = 0.05. Older group = Baby Boomers + Generation X (n = 26); younger group = Generation Y + Generation Z (n = 24). All 50 respondents provided experience data.*

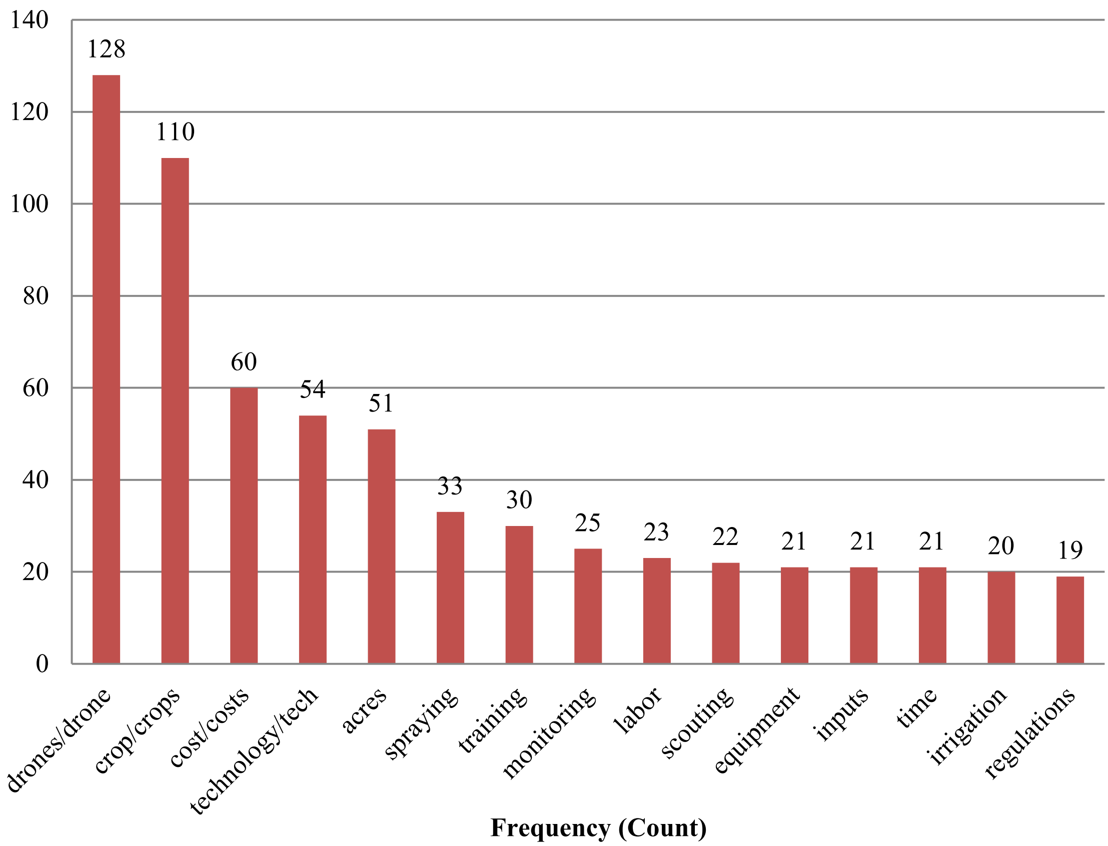
The statistical findings indicate that older-Generation producers have had significantly greater cumulative years of farming experience than younger-generation producers. Furthermore, the survey contained generational-specific questions to allow for a better understanding of how each generation differs regarding their comfort level with technology as it relates to their farm size. Unfortunately, the survey did not include a single comparable question related to technological comfort and/or farm size between all four generations, and therefore, direct cross-comparisons cannot be made. Since the years of farming experience variable was asked in equivalent form across all areas, valid drivable statistics were calculated.

5.9 Word Frequency

Prior to analysis, standard text-cleaning procedures were applied. Common stop words such as articles (a, an, the) and prepositions (in, on, near, of) were removed. Similar terms were combined to improve interpretability, including singular and plural forms (e.g., drone/drones, crop/crops, technology/technology) and related terminology (e.g., drone, unmanned aircraft). The content analysis followed standard qualitative text-analysis procedures commonly used in applied agricultural economics research (Lu et al., 2022).

A word frequency analysis of the open-ended survey results revealed the terms most frequently used by respondents in describing drone technology.

Figure 5.6: Word Frequency Distribution from Open-Ended Survey Responses



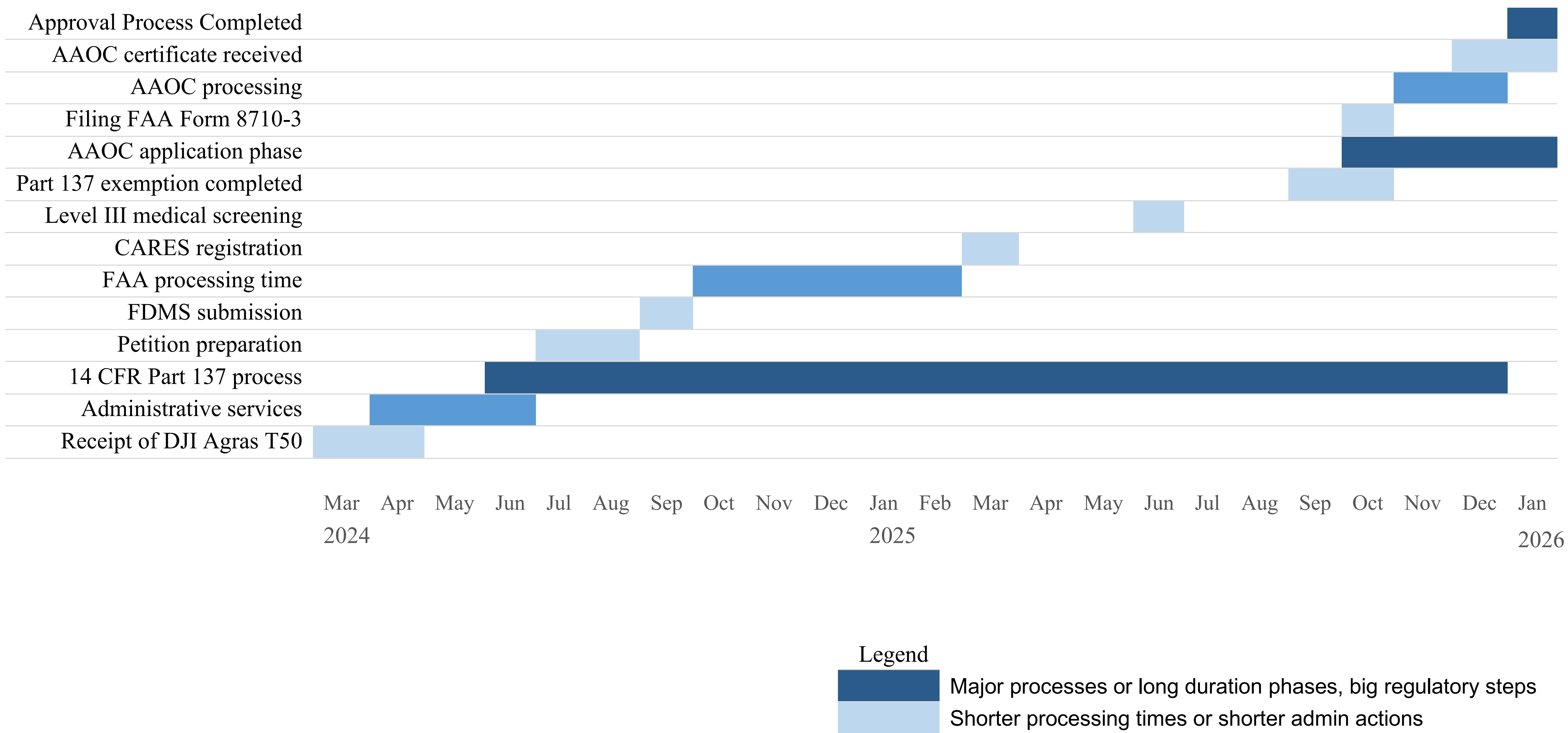
The words "cost" and "spray," as well as "training" and "regulations," are strategically linked together through their high frequency in the responses of all respondents and support the quantitative findings of how producers primarily view drone technology as costs and operational use rather than to generate revenue or potential market positioning. Furthermore, the generality of the terms "training" (30 mentions) and "regulations" (19 mentions) highlights that human capital development, and the complexity of regulations are significant considerations in decision-making by all producers, regardless of generation. In addition to single-word frequencies, pairs of words that frequently occurred together were examined informally to identify common themes, although a full bi-term statistical analysis was not conducted.

5.10 Personal Case Study: FAA Registration and Exemption

This research field testing was performed at the Fresno State Farm agricultural farm. Within the farm, there were approximately 100 acres allocated for spray applications (See figure A.1 in Appendix A). It was possible to examine drone usage under actual conditions rather than theoretically. Specifically, the evaluation included silage corn, winter wheat, and alfalfa cultivated at the farm. In terms of drone assessment, three areas could be distinguished: the quality of spray coverage, drone operation's efficiency including time spent, labor involved, and productivity, as well as field monitoring possibilities.

A real-world example of drone regulatory barriers and financial barriers cited by respondents in the survey can be found in the FAA registration and exemption for a DJI Agras T50 agricultural drones through a university-based, research-focused FAA review process. The direct regulatory costs of obtaining the exemption and Part 137 certification included FAA drone registration ($5), the FAA Part 107 knowledge test ($175), and approximately $2,000 in legal or consulting fees to prepare the Part 137 exemption petition. Associated costs for FAA application/inspection fees (~$500–$1,000), training programs (~$500–$2,000), and state pesticide applicator licensing (~$50–$300) further increased the financial investment required for compliance. Figure 5.7 depicts the timeline of events related to the FAA registration and exemption process and the cost associated with obtaining an operational agricultural use certificate for the T50.

Figure 5.7: Timeline of events for FAA Registration and Part 137 Exemption Process for DJI Agras T50 Agricultural Drone



The total time from when the DJI Agras T50 was received in March 2024 to when the Agricultural Aircraft Operator Certificate (AAOC) was issued in December 2025 was 22 months. In total, there were numerous examples of the FAA not meeting the estimated processing timelines for its Exemption Petitions due to requests for additional information, time delays related to the aircraft registration through the Civil Aviation Registry Electronic Services (CARES) registration system, and the FAA's requirement that each Part 137 operator hold a valid Level 3 FAA Medical Certificate.

This case study also provides a concrete operational efficiency comparison. A traditional ground application (used through tractor-mounted boom sprayers) of agricultural inputs to 10 acres of a field would take 2 hours and require 60 minutes of setup time, for a total of 120 minutes of operational time. However, using drones, the DJI Agras T50 could treat 10 acres in 27 minutes, using only 15 minutes of setup time. Based on these estimates, the total time required for the traditional method was 120 minutes, while the drone required 27 minutes. This results in an operational efficiency ratio of about 4.4:1, meaning the drone completed the same task in less than half the time. Although using them to treat 100 acres of land is significantly more efficient than traditional methods, it took nearly 2 years to be able to operate.

Based on the estimated operational efficiency, the delay of approximately 22 months before approval represents a substantial opportunity cost. If the drone had been available during this period, producers could have completed field applications in less time and with reduced input costs. Although exact revenue losses cannot be calculated without farm-level production data, the delay likely resulted in foregone operational savings and reduced profitability during the waiting period.

A further dimension which was apparent during the process of this research was the way geography affects drone application (See figure A.3 in Appendix A). According to the findings, the Fresno State Farm is located within 4.6 miles of a regional airport and approximately 44 miles away from the Lemoore Naval Air Station. As such, in addition to the regular requirements of the FAA, several more requirements must be met. They consist in the mandatory receipt of permission for flights, observing strict altitude limits, retaining control over the drone in sight, as well as being aware of other airplanes' movement. Though these measures are aimed at ensuring safety, they require some preparation and planning before every flight. Thus, there might be extra costs associated with drone application due to an increase in preparation, coordination, and compliance activities before operation starts. As a result, it will not look advantageous to adopt the technology for producers based in similar locations.

In accordance with the collected field data, where the drone performed an operation on 10 acres in around 27 minutes, the working rate equals about 22 acres per hour. After that, the formula can be modified to find field efficiency, which reflects the ratio between real and optimal performance of the equipment. Usually, manufacturers specify nearly perfect working conditions, which rarely occur in practice because of several reasons: refills, battery replacement, turns, synchronization issues. In other words, although real-life effectiveness of drones exceeds the effectiveness of alternative devices, effective field efficiency may be lower due to numerous factors. However, this situation does not change the fact that drones operate significantly faster than alternative devices.

From another perspective, one should note that drones possess an advantage in terms of flight time, the difference becomes less evident when considering additional preparations, setup, and operations. Completing certain operations faster will have a considerable effect on the crop production cycle. Specifically, this aspect may prove valuable for the period of crop growth. This issue should be viewed critically because of multiple challenges that arise when using drones for agricultural purposes. For example, regulation and training issues will influence overall performance of drones negatively.

CHAPTER VI: DISCUSSION

6.1 Key Findings

Survey data indicate that drone technology provides several operational benefits such as precise resource application, reducing input volumes and saving time on agricultural activities. In addition, respondents emphasized everyday operational benefits over potential financial gains. In this regard, drones appear to be helpful for increasing productivity rather than providing immediate profits for producers.

Nevertheless, the adoption rate seems to be lower than expected considering all those benefits. First, one of the major issues faced by producers appears to be linked to regulation and licensing requirements. On the other hand, part of the problem may relate to regulation itself. On one hand, federal-level regulatory measures, such as FAA licensing, apply to all regions in the U.S.; however, producers may still be required to comply with some state-level regulations as well, thus adding another dimension of complexity. For producers, this may complicate matters; additionally, the process may seem less predictable to them. Moreover, compared to other factors such as costs or technological know-how, compliance seems to be an acute problem in the implementation of drones in agricultural production. In addition, several participants pointed out the need to spend time learning the technology, which makes its adoption challenging, especially during harvest time.

Secondly, there is also an issue regarding the approach to technology evaluation by producers and its adoption. Many responses show a focus on short-term and easily measurable benefits, such as savings or efficiency gain. Consequently, regardless of technology performance, the choice to utilize it appears doubtful. These observations help explain why adoption remains relatively low despite recognized benefits.

6.2 Comparison to Theory

Based on Rogers' theory, the findings obtained in the study appear to lie somewhere in the middle between early adopters and early majority phases of innovation adoption. Nevertheless, considering that the participants of the study are likely to be more open-minded towards innovative technologies than the rest of producers, the stage of adoption may be somewhat underestimated, given that survey participants are likely more open to innovation than the broader producer population. According to the national statistics data, drone usage in the agricultural sector is rather low now. Hence, agriculture producers seem to be at a rather early stage of adoption. Rogers’ framework highlights that certain characteristics of technology can affect the pace of adoption, among which the complexity of innovation is one of the main issues. Therefore, all those problems associated with regulation, training, and analysis can lead to complex adoption processes.

Observed responses align with Rogers’ emphasis on social factors, as adoption can be facilitated through cooperation of younger producers willing to try something new and older members of the community, who provide expertise and endorsement. However, this process requires certain conditions such as integration of new technology into existing routines.

6.3 Non-Monetary Costs of Investing in Human Capital

The non-monetary cost of developing human capital for using drones is one of the many areas typically overlooked by traditional cost-benefit analyses (McFadden et al., 2023; Griffin et al., 2004). To operate effectively, it requires a high level of proficiency in a variety of technical fields, including remote sensing and multispectral image processing, as well as adhering to aviation regulations. The professional training that traditional agriculture producers acquire does not encompass any of these skill sets. Therefore, a producer who decides to implement this technology in their operation is, by default, agreeing to what are potentially hundreds of hours of developing competency in fields that they are unfamiliar with, instead of completing planting, harvesting, marketing, and other revenue-producing activities. This is reflected in text data, with the word "training" coming up 30 times within the write-in responses to open-ended questions asked to respondents. This investment in human capital is largely not reflected in financial calculations because it does not appear on a balance sheet; instead, it is represented by the number of evenings spent watching training videos, weekends attending training workshops, and the mental capacity required to grasp an entirely new set of technical language.

6.4 Known Costs Compared to Unknown Benefits

Another common theme highlighted through both quantitative and qualitative data is the asymmetry of certainty associated with the costs of adopting, compared to the uncertainty of receiving a benefit from adopting a drone. For example, a producer can easily determine the cost for a DJI Agras T50, fees for a Part 107 certification class, and the cost for registering an aircraft through the FAA and therefore know with certainty how much has been invested in them. However, the producer does not know how much they will earn in return for their investment. Crop prices and weather events are unpredictable and often outside of the producer's control; pest pressures are often impossible to accurately predict; and the value of early detection of stress in it depends on whether any suitable option exists to address that stress, whether that option is affordable at that time, and whether there would be an impact on yield at the time of harvest had the producer not taken action. As a result of these uncertainties, 53% of respondents indicated that they are "still evaluating" how drone technology is profitable compared to other technologies; this mirrors the findings identified by Popp, Griffin, and Pendergrass (2002) in their previous research on precision farming and is still present today after 20 years of uncertainty surrounding agricultural commodity returns.

In addition, there is the issue of whether farmers choose to own the equipment they need for working with drones themselves or rely on outside help. Producers will not necessarily want to purchase and maintain such technology themselves; in particular, some might be more interested in engaging with third parties that offer custom drone services or products. This dichotomy may be important in understanding producers' perceptions of cost, risks, and benefits associated with adopting drones.

6.5 Generational Differences and Statistical Significance

Statistical evaluations reveal a pattern of generational differences; in other words, farm size, comfort level with new technology, and willingness to invest in new technologies do not differentiate younger producers from older producers, but rather the amount of operational experience each has. Producers that are representatives of the Baby Boomer generation have decades of experience to draw from regarding transitional periods of new technologies; for example, producers have successfully transitioned to utilizing GPS guidance systems and precision applications of variable rate technologies; therefore, while the Baby Boomer producers have demonstrated that change is not challenging for them, they still have questions regarding migrating to this technology because they will need to develop new skill sets different from mechanical technologies.

Additionally, it should be noted that the generationally differentiated survey question structure limits the ability to compare technology comfort levels directly across the generations (Baby Boomer respondents were asked about how comfortable they feel when using technology to farm, whereas Generation Z respondents were asked how intuitive they think drone technology will be to utilize in their farming operations). These concepts are related but not the same; therefore, training programs developed to support younger generations' development of competence in utilizing drones should not automatically assume that because younger generations are comfortable with using technology in all aspects of their lives, they will also be competent in using them; instead, these training programs should be aimed at providing younger generations with a specific training based on their level of competency in drone technology.

6.6 Implications for Extension, Policy, and Industry

The research indicates that supporting infrastructure for technologies may be as vital as the technologies themselves. Although drones seem to offer clear operational advantages, most producers still struggle with implementing them. The first noticeable trend is that regulatory barriers may be quite significant. Unlike other potential barriers, such as price or technical complexity, regulatory demands and their implications for license acquisition may hinder early-stage adoption.

However, knowledge gaps and skill deficits remain another barrier to adoption. Here, extension services may prove useful. Practical training programs going beyond basic drone operation to include data analysis and applications could contribute to making drones seem more viable and attractive to adopt (Murphy & Bergman, 2020). Peer learning could also play a role; for example, it would benefit producers if they saw their counterparts applying drones successfully under similar circumstances. However, the growing complexity of the new technology in question may also increase pressure on the capacity of Extension services. Today, supporting adoption of drone technologies not only involves conducting technical training related to using and operating drones; it may require additional help, including assisting producers in complying with relevant regulations and analyzing data. Under such conditions, Extension systems are under increasing stress and may require expansion and adaptation.

Adoption rates may also depend on whether appropriate support infrastructures exist. If there are few options for professional consultation, repairs, or related services, technology seems riskier to implement. Thus, adoption is not only a matter of human choice but also of the longer-term development of the infrastructure around technology. With the provision of more support tools and channels, adoption may become less risky.

For policymakers, the case highlights the significance of regulatory timelines as a potential hindrance to application. Delays in licensing and certification may offset the efficiency gains provided by drones. Thus, streamlining parts of the regulatory process or providing more consistent deadlines may contribute to overcoming barriers to adoption. Aside from extension agents and policymakers, the private sector may also play an important part in encouraging adoption. Not all producers will have sufficient time or resources to manage all components of drone usage on their own. Particularly, many producers may find it difficult to meet certain regulatory aspects related to using such technology or managing and analyzing data collected via drones. In this context, private organizations may provide help by offering comprehensive service solutions, including turnkey operations, consulting, subscriptions, etc. For the industry, the case suggests that manufacturers are not necessarily driven by technological characteristics. Instead, the perceived value that technology offers appears to be the key factor. Consequently, highlighting how drones can improve productivity or lower production costs could be a better strategy than stressing their technical features.

CHAPTER VII: LIMITATIONS

There are several limitations to this research project. First, only 50 respondents completed the survey; however, only 11 respondents provided the necessary farm demographic data (i.e., farm size, farm region, and primary type of farming) to provide meaningful interpretations of those findings across the 50 respondents; therefore, the data from those 50 respondents cannot be generalized to all farmers utilizing drone technology in the United States. Second, the survey was conducted online, therefore introducing self-selection bias into the sample pool, which may adversely impact how representative this sample pool is of the total population of drone-using agricultural producers in the United States, given that producers who are more technologically proficient are likely to be more comfortable completing an internet-based survey.

Third, a differentiated question design based on an individual's age limits the ability to directly compare the responses across the generations; hence, the barriers data was provided primarily by the Baby Boomer generation (n = 11), while motivation and benefits data can be attributed to the Generation X (n = 15) and Generation Z cohorts (n = 12), respectively. Fourth, many of the Baby Boomer respondents were consistently located in the Mountain Plains and Midwest regions; therefore, the survey results do not adequately represent the full geographical diversity of producers in the United States. Fifth, all outcome data collected from the survey were self-reported perceptions. Finally, the broad design looks at the point-in-time view of the data collected rather than a trajectory of the data; therefore, data would need to be collected to assess how producers' perceptions and adoption rates change over time as drone technology matures, and regulatory processes evolve for the use of commercial purposes.

The regression analysis was not conducted due to the limited sample size. A small sample size is not ideal for regression analysis, as it dilutes the statistical power of the study, and there is the potential risk that the results of the regression analysis would not be representative of the population. The sample size for this current study increases the chances of false negatives. Therefore, the analysis was limited to descriptive statistics and summary statistics as opposed to correlation studies and predictive models. Future research should include a larger survey to increase the sample size with the aim of having a representative sample and a sample size that allows for the detection of significant relationships. A larger sample size will improve the generalizability and scalability of the study findings. For example, if the results of the study are to be applied to the demographics considered, the fact that fewer than 30 of each demographic were interviewed significantly lowers the reliability of these results.

CHAPTER VIII: CONCLUSIONS

This research provides a study that analyzes the multi-generational adoption of drone technology among agricultural producers, which is grounded in Rogers' Diffusion of Innovations model and supported by the personal case study on FAA drone regulations and statistics supporting its adoption. The results of the analysis suggest that technology has measurable benefits associated with production, the majority of which are the reduction of inputs used and increased time efficiencies across all generations of agricultural producers. The ultimate barriers that producers may experience when they attempt to adopt (technical knowledge, regulatory complexity, cost/benefit uncertainty) will continue to delay the adoption of drone technology until it enters the early majority phase of the diffusion model.

Extension educators need evidence to develop targeted educational programs to assist producers with their identified knowledge gaps related to using drone technology, particularly in the areas of data interpretation and understanding the regulatory process. Extensions must educate federal policymakers on the current FAA Part 137 exemption process to enable producers who would benefit the most from using it to speed up the time it takes to diffuse the technology throughout U.S. agriculture while maintaining safety. Stakeholders in the agriculture industry (manufacturers, agricultural bankers, and data analysts) need to recognize that farmers evaluate based on economic considerations rather than technological considerations; therefore, providing farmers with evidence that demonstrates an economic ROI from using drone technologies will be more effective than providing farmers with technical specifications.

The findings presented in this research also have long-term implications. The increase in drone adoption will result from the transfer of farmland and management authorities from the Baby Boomers to the younger generations, who are typically more comfortable with using technology than previous generations. However, younger generations will require financial resources to support their technology investment and training resources to translate their knowledge of technology into practical applications for use in precision agriculture.

Future research should depend on larger, random samples to enable direct comparisons across generations. The future direction in U.S. agricultural production is uncertain; however, this research provides evidence that drone technology will improve operational efficiencies among all generations of agricultural producers, and the pace at which knowledge gaps, regulatory barriers, and cost-benefit uncertainties are closed will ultimately determine the speed of this technology diffusion within agriculture. Extension educators, federal aviation policy makers, and agriculture industry stakeholders play key roles in closing the gaps that exist with respect to drone technology adoption within agriculture. However, if stakeholders fail to coordinate their efforts before U.S. agricultural producers fall behind international competitors who have embraced drone technologies at a much more rapid pace, the future of their use in agriculture will be limited to an early phase within the agricultural industry. This research represents a foundation to guide future research in establishing an effort to keep our farmers educated on the upcoming processes as time progresses.

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APPENDIX A: PERSONAL DIARY - FAA REGISTRATION AND EXEMPTION JOURNEY FOR THE DJI AGRAS T50

March 14, 2024

Today, we received the DJI Agras T50, and I must admit that in person, the machine looks more intimidating than what we had seen in any promotional material. Fully loaded with spray solution, the drone will exceed 200 pounds, and it comes in at 88 pounds empty, which means it is certainly not designed for weekend hobbyists. (DJI 2025) The coaxial twin-rotor propulsion system, along with a 40-liter spray tank, makes it clear that this is commercial agricultural equipment. I stood there on the university warehouse floor watching the unpacking of the unit and started to worry that trying to get the thing in the air may, in fact, prove to be a lot more hassle than simply operating it once it is airborne.

Figure A.1: Aerial view of the specific agricultural test plots (approx. 100 acres) designated for drone spray operations

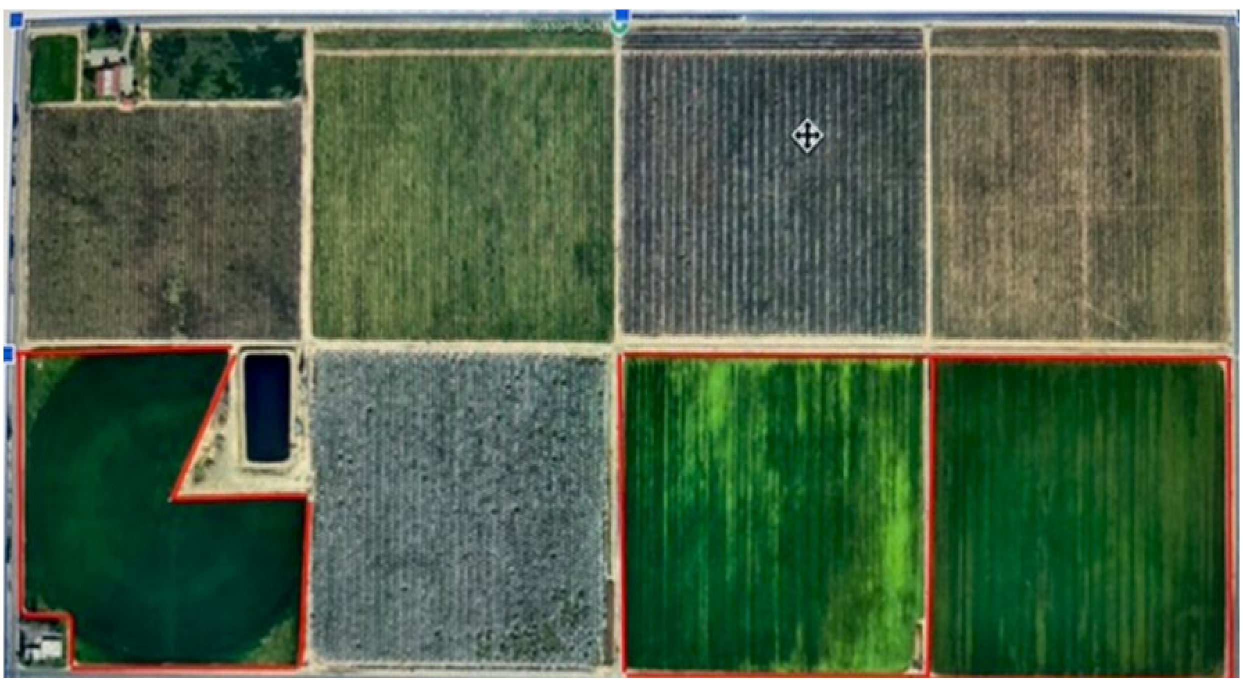


Figure A.2: FAA Registration and Exemption Process Timeline for the DJI Agras T50 (March 2024 – January 2026)

	March 14, 2024	April 28, 2024		June 6, 2024		August 19,2024					January 11, 2025				May 3, 2025				September 22, 2025			December 8, 2025	January 15, 2026
Activity	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 13	Month 14	Month 15	Month 16	Month 17	Month 18	Month 19	Month 20	Month 21	Month 22	Month 23
Receipt of DJI Agras T50 (The drone) and unpacking	x																						
Administrative services		x	x																				
14 CFR Part 137				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
1. Petition preparation				x	x																		
2.Submission of petition on Federal Docket Management System (FDMS)						x																	
3. Processing time prior to first response from FAA							x	x	x	x	x												
4. Registration of drone through Civil Aviation Registry Electronic Services (CARES) (Revisions to submission)												x											
5. Level III Medical Screening for certified pilot															x								
6. Completed 14 CFR Part 137 exemption																			**x**				
Agricultural Aircraft Operator Certificate (AAOC)																			x	x	x	x	
1. Filing of FAA Form 8710-3 and copy of exemption number																			x				
2.Processing time																				x	x	x	
3. Completion and receipt of AOCC certificate																						**x**	
																							X

Daniel, our licensed pilot who has held his Part 107 certification for five years, cautioned all of us in the beginning about the potential regulatory obstacles we would have to address. According to him, anything over 55 pounds is considered an "aircraft" in the eyes of the FAA, and therefore, we would have to navigate through a potentially long and drawn-out certification and approval process like traditional aviation. (Federal Aviation Administration 2024) Until I began looking at the FAA website regarding the dispensing of chemicals and the application of agricultural products, I had no idea of just how serious Daniel was about that point. The 14 CFR Part 137 establishes the scope and purpose behind the FAA regulations governing agricultural operations, and since we are over the critical 55-pound threshold, we also need exemptions from the requirements outlined in Parts 61 and 91. (Federal Aviation Administration 2024) Essentially, that means we need to seek exemptions from three entirely different sections of the FAA regulations, each section with specific requirements and timeframes for approvals. The amount of patience I was initially hoping I would not have to exercise through this entire process just changed dramatically.

April 28, 2024

Daniel has begun walking us through what the exemption process will require, and the complexity is staggering. Even though Daniel already holds his Part 107 Remote Pilot certification, I learned today that I will still need to complete the required online training programs before I can assist with any flight operations. (Federal Aviation Administration 2025) Anyone else on our team who wants to operate the T50 will need to complete the same training. The FAA does not make exceptions. It feels overwhelming. Meanwhile, our $35,000 drone sits in the warehouse, collecting dust and depreciating while we push paper.

Daniel stated that training includes airspace classifications, weather patterns, and emergency procedures, which are all important for commercial operations. (University Part 107 Training Documentation 2023) Most of my contributions to this project have focused on coordinating, documenting, and providing various administrative services. However, I have also experienced first-hand how seriously the FAA takes commercial drone operations concerning their training needs. The financial burden of this process is already weighing on us. Every day that it sits, it represents lost potential revenue and wasted investment. We could have been conducting spray operations months ago if the regulatory pathway were simpler.

June 6, 2024

We are finally ready to begin Part 137 exemption process. Daniel has gathered the preliminary documentation, and now the real waiting game begins. The FAA website states that petitions take at least 120 days to process. (Federal Aviation Administration n.d.) Four months minimum, assuming nothing goes wrong. The frustration is mounting. Our T50 has now been sitting in storage for nearly three months, and we have not even submitted the petition yet. The preliminary paperwork alone has consumed weeks of effort. Daniel keeps reminding me that this is normal for agricultural drone operations, but normal does not make it any less painful. It cost nearly $35,000, and every month it sits unused and feels like money burning. I calculated that if we had been able to operate immediately, we could have already generated significant returns on our investment. (14 CFR § 11.63(d))

August 19, 2024

The petition preparation process has consumed the past two months of our lives. I have spent countless hours compiling the required documentation, including the DJI Agras

T50 pilot and operating manuals, packing list, weight configuration specifications for proposed operations, proposed operational procedures, and a complete list of specific regulatory exemptions being sought from this agency. The FAA has requested that the petitioner include a detailed explanation detailing the rationale for requesting the exemptions and demonstrate that granting the exemptions will not adversely affect safety.

We submitted our petition through the Federal Docket Management System (FDMS). The FDMS is a digital system that assigns a docket number for tracking purposes, and now we wait. (Federal Docket Management System n.d.) As Daniel has pointed out, petitions are published on regulations.gov and are subject to public comment, so he has spent some time researching other petitions to see how other applicants structured their submissions. Some of the applicants he reviewed had engaged the services of aviation attorneys specializing in the petition process. Unfortunately, our budget does not allow us to afford outside legal counsel; hence, we heavily referenced the petitions submitted to the FAA by AgriFlight and MidFlight. (University Part 137 Process Documentation 2023) Time will tell if that is sufficient.

January 11, 2025

We have just received our first response from the FAA regarding our petition for exemption, now five months after our submission. Unfortunately, we did not receive an approval; rather, we received a Request for Information (RFI) seeking more information about our intended operational procedures and confirmation of Daniel's qualifications. They are requesting validated proof of Daniel's Remote Pilot Certificate and the registration documentation for the drone, including the embedded serial numbers and confirmation of ownership. The delays are excruciating.

This changed the game entirely because the T50 weighs more than 55 pounds and therefore cannot use the online FAA drone Zone registration process for smaller recreational or commercial drones. We had to register the T50 using CARES (Civil Aviation Registry Electronic Services) or via the U.S. Postal Service. (Federal Aviation Administration n.d.) We tried the online route first, thinking it would save time, but we experienced time-out issues during the final phase of submission every single time. After several failed attempts, we decided it was best to mail the application using certified mail with tracking. Finally, weeks later, we received an Aircraft Registration Certificate from the FAA with an N-number, which is the official identification number for our drone in the national airspace. Seeing this number on the Certificate represents a milestone, although we still have a painfully long way to go. The drone has now sat unused for ten months.

May 3, 2025

As of today, we learned upon contacting the FAA that everyone operating under a Part 137 exemption for agricultural aircraft operations will need to have a valid medical certificate stating that the operator is fit to fly. Therefore, Daniel will need to undergo Level III Medical Screening by an FAA Aviation Medical Examiner (AME) before being able to operate the T50 over crops. (Federal Aviation Administration n.d.) We were able to find a doctor who agreed to conduct the screenings approximately one hour away, and Daniel has been scheduled to see that doctor before the end of the month. The medical screening costs have been estimated at $125 to $200, depending on the AME (University Part 107 Training Documentation 2023).

One way of being completely overwhelmed in pursuing our goal is when we look collectively at how much money this process has cost us. When we total the registration fees, medical screening costs, administrative expenses, and the opportunity cost of a drone sitting idle for over a year, the financial impact is staggering. For a university program researching on a shoestring grant budget, every dollar must be justified. The T50 could have paid for itself by now if we had been able to operate it. Instead, we continue hemorrhaging money on a piece of equipment that remains grounded.

September 22, 2025

After 18 months of waiting and moving at a snail's pace, we have finally received our exemption number! We read and reread the email to confirm I was interpreting the information correctly. We had received an exemption! The FAA granted our request to operate the DJI Agras T50 within the specified scope and with the restrictions outlined in that exemption. There are presently over 1,700 individuals who have been issued operator certificates by the FAA for operating agricultural drones weighing over 55 pounds. (Federal Aviation Administration 2025)

However, even though we have received our exemption from the FAA, we are still not able to do any field operations because we need to obtain an Agricultural Aircraft Operator Certificate (AAOC). To receive the AAOC, we had to file FAA Form 8710-3 by email along with a copy of our exemption number. (Federal Aviation Administration 2024) Any discrepancy in the name on the exemption document compared with the name on the application would result in us being required to start over. The drone has now been sitting for 18 months.

December 8, 2025

We have received our AAOC! Approximately two years after we unboxed the T50 into our university warehouse, we have now obtained all required approvals and permissions to conduct agricultural drone operations under the FAA in the National Airspace System. We will finally be able to do what was intended: conduct precision application of pesticides, herbicides, and fertilizers over 100 acres in a fraction of the time required for any spray tractor.

I wish someone had laid out realistic timelines for us from the initial stage. The FAA's stated timeframe of 120 days for processing an exemption would be accurate for an individual who does not encounter delays and additional questions. For months, I did not know if or when our petition would be approved because the reviewer's desk was piled high with other requests for action. When we responded to a request for clarification, it was as if we were starting the petition over again, so each response took me several months to get to the submission stage. We waited for almost two years and spent a lot of money to find out if we were ever going to receive a final decision and experienced a lot of frustration during our waiting period.

Technical Summary and Calculations

A typical tractor-mounted boom sprayer in operation can treat 10 to 12 acres per hour. This does, however, come with a considerable amount of setup time associated with hitching and tank mixing that typically will take 45–60 minutes. If we take 100 acres of the target site to spray, it will take roughly two total hours to use a ground rig to complete that function. In comparison, the DJI Agras T50, as an example, can be deployed in less than 15 minutes and has a spray efficiency of 50 acres per hour; therefore, completing all operations will take approximately 30 minutes, or approximately one-fourth as long as the current operation being completed using a ground rig.

To validate the above comparisons of efficiency, the following formula for operational efficiency was used:

Total Operational Time = (Target Area ÷ Application Rate) + Setup Time

For the tractor mounted boom sprayer: (100 acres ÷ 10 acres/hr.) + 60 minutes setup = 10-hour application + 60 minutes setup

= 660 minutes (11 hours) total.

For the DJI Agras T50 drone: (100 acres ÷ 50 acres/hr.) + 15 minutes setup 2 hours application + 15 minutes setup

= 120 minutes + 15 minutes

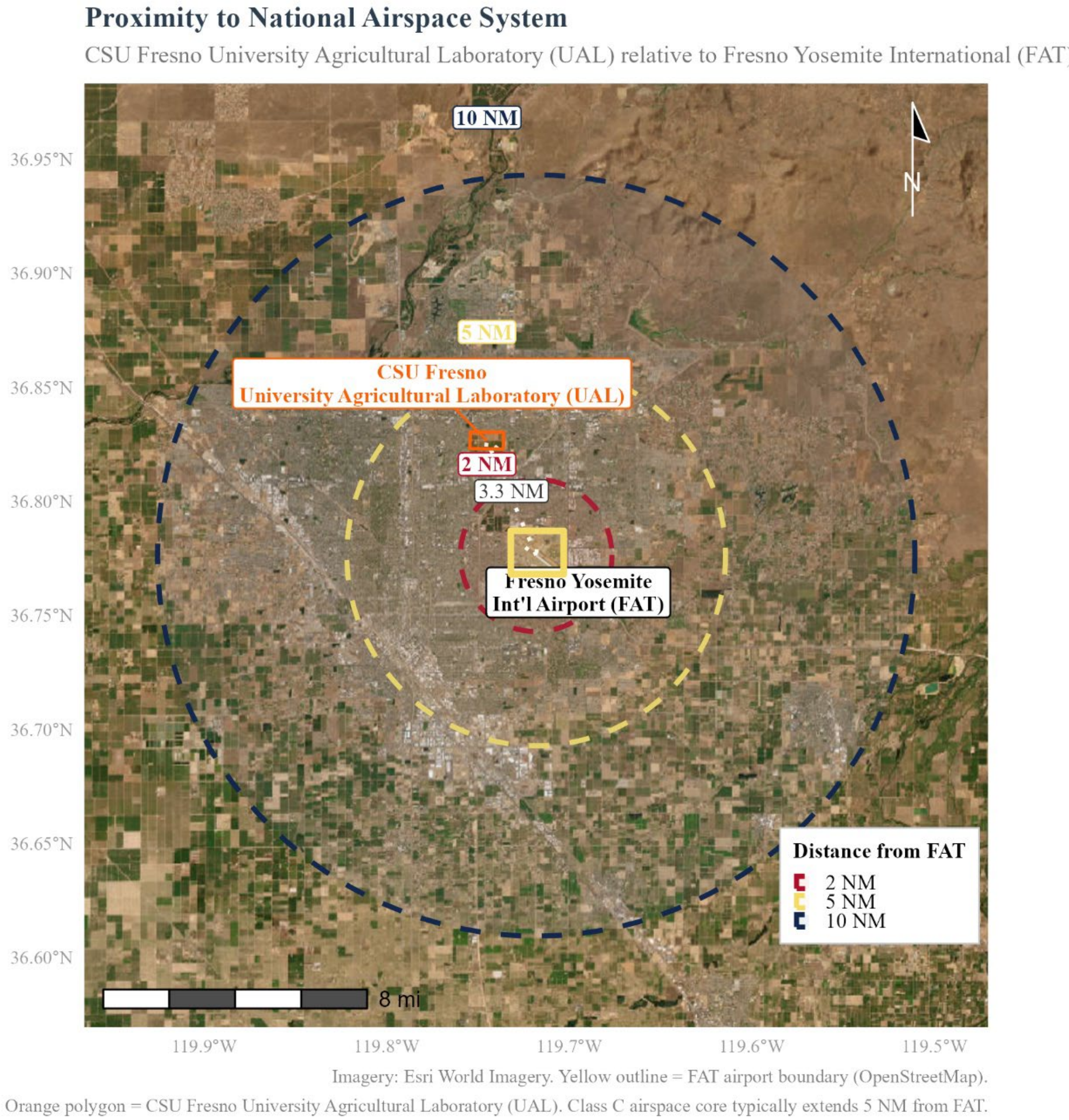
= 135 minutes total (2 hours 15 minutes)

Comparison Factor: 660 minutes ÷ 135 minutes ≈ 4.9

The conclusion is that a drone can complete the same task (apply pesticides/fertilizers) in less than 20% of the time it takes a ground rig to perform the same task, which is about 5 times faster than with the standard boom sprayer.

Figure A.3: Sectional view showing the proximity of the operational fields (top left) to Fresno Yosemite International Airport (bottom right).

Figure A.4: Proximity to National Airspace System



January 15, 2026

We have not yet completed our first spray operation with the T50, but we are finally preparing for it. All commercial pilot operations are to have details of each operation entered in a logbook, which must contain date, location, duration, and the chemicals used to spray the subject(s) during the operation. (14 CFR § 137.71) After two years of navigating this process, we are on the verge of finally putting this equipment to its intended use. The anticipation is palpable, but so is the exhaustion from this grueling process.

If I could give any advice to anyone beginning down the path of working through FAA regulations, that advice would be to get started early, diligently document every aspect of the request, and be prepared for delays all along the way. There is a process put forth by the FAA to provide for the safety of the public, and I am very much in support of that objective. However, navigating through federal regulations requires an enormous amount of patience, which oftentimes demands extreme tenacity. I suggest reading and interpreting the official FAA guidance found at FAA.gov. I also suggest reading successful examples of other petitions on regulations.gov. Additionally, I recommend reaching out to others who have completed the process.

The T50 now carries more than just agricultural chemicals; it also carries two full years of continuous effort, a stack of federal forms completed and revised more than once, and the weight of a $35,000 investment that sat idle while we worked the system. We earned every flight hour ahead, and I genuinely hope no one else will endure such an unnecessarily difficult process to operate agricultural equipment.

APPENDIX B: CONSULTANCY APPLICATION AND SWOT ANALYSIS

Considering the results presented in the study, it is feasible to develop a consultation business that will help agricultural farmers utilize the benefits of drone technology. Although drones can be helpful in terms of saving money and increasing efficiency, it seems that many of the producers do not know how they can incorporate this innovation in their farms. The issue may not be rooted in insufficient awareness. However, it seems that many of the producers face some issues with the transition.

This is why developing consultancy business may help. Instead of providing general information, consultants will assist with the integration of drones in farming by giving the necessary instructions to individual clients. It may be easier to convince farmers to try out drones if they do not find it too difficult. Since agriculture is associated with making decisions quickly, it seems that adding more steps that require knowledge, such as obtaining FAA certificate, may only add unnecessary burden. With consultancy services, people will be able to complete all the steps without additional effort.

One of the key points at which consultation may prove useful is certification process. According to the study results, FAA approval and exemption process can take a lot of time, involve many steps, and confuse the producer. The personal drone diary provided showed that it can take two years or even more to get through the entire process. Thus, many farmers might not even consider using drone technology because of that. Consultants may facilitate obtaining approval by avoiding common mistakes and helping people keep records.

Training seems to be another important point. As indicated by several interviewees, they found themselves unable to properly work with drones, although they had already understood what drones do. Learning how to work with them can be only one aspect of training. The producer will need help regarding flights, picture analysis, and ways of proceeding with the information received. Without the latter, this technology will remain just that – technology without a purpose. Consulting services will include courses, practical exercises, and perhaps individual consultations that would help producers feel more confident. For some of them, personal experience may become more useful than reading a manual or watching online video tutorials because they must use the equipment practically.

Consultants may also find it useful to help manufacturers decide whether drones are right for them or not. There cannot be just one answer to this question because different producers and farms may have varying conditions. Drone usage may bring many benefits in some cases but less in other ones. A consultant could help make this decision based on real numbers, considering such aspects as input saving, time saving, possible increases in efficiency, time needed to learn how to work with drones, and regulatory processes. Thus, producers could get to know all sides of the story rather than listening to a biased speech from manufacturers.

Yet another service that consultants may consider providing is continuous support services. After a producer has already decided to use this new technology, there may still be many things that he/she needs help with. New technologies develop rapidly; therefore, producers will have to stay up to date, learn new software, and analyze data obtained using drones. Not all producers might want to deal with this on their own. A consulting service could provide them with seasonal consultations, help to solve various problems related to drones or any other issue, and help with data analysis.

The consultancy can also be enhanced through partnerships. Collaboration with extension offices or agricultural organizations can help enhance credibility and target extra farmers. While the extension office provides training and information to farmers, it may not have sufficient resources to train on the advanced use of technology. Therefore, an advisory service can supplement the training and emphasize implementation. The consultancy service may appear credible because of the partnership with extension offices. The producer may be more confident to trust the consultancy if he fears new ways of making money.

On the other hand, there are certain challenges to address as well. First, some producers may be hesitant to pay for the advisory services since they do not see the benefit of drones. Some producers might choose to hold off buying drones until the drone technology becomes cheaper and easier to use. Other farmers may prefer peer learning and adopt what the neighboring farms are using without paying for the training. The above issues might affect the demand for advisory services, especially during the initial stages.

The next challenge is the competition from big firms and manufacturers. When the drone manufacturers start to integrate advising services within their products, small consultancy firms will face competition. To stay relevant, the independent consultancy firm will have to offer flexible advisory services based on the needs of the client. It is hard to predict the future market trend, but there is a possibility of stiff competition over time.

Another challenge is the regulatory environment. If the certification process is simplified or becomes quicker, the demand for advisory services may decline over time. Alternatively, when regulations become complex, there will still be a need for advisory services. In summary, it is not easy to predict the future of the consultancy model because of the uncertainties associated with drone technology. However, based on the current situation, there seems to be some demand for advisory services.

Overall, the proposed drone consultancy is directly connected to the results obtained from the literature review. The producers seem to understand the benefits of drones; however, there are several practical issues affecting adoption. The consultancy service will focus on training, regulatory compliance, and implementation. While there will be some demand for the service, it will depend on the ability of the consultancy firm to adapt to different producers' needs.

SWOT Analysis

Strengths	**Weaknesses**
Addresses clear barriers (regulation, training, knowledge gaps)	**Demand may be limited if producers are hesitant to adopt**
Provides practical, hands-on support tailored to farms	**Requires specialized knowledge of both agriculture and aviation rules**
Can improve efficiency and confidence in using technology	**Initial setup may require time to build trust with producers**
Flexible service model (training, compliance, consulting)	**May depend heavily on local market awareness**
Opportunities	**Threats**
Growing interest in precision agriculture technologies	**Regulatory changes could reduce need for consulting support**
Increasing need for training and compliance assistance	**Larger firms or manufacturers may offer similar services**
Potential partnerships with Extension services or universities	**Slow adoption rates may limit client base in some regions**
Expansion into data analysis and farm optimization services	**Economic conditions may affect willingness to invest**

APPENDIX C: SURVEY QUESTIONS

Section 1: General Questions (All Respondents)

- What year were you born?
- What region are you from?
- What is the approximate size of your farm?
- What type of farming do you primarily do?
- How many years have you been farming?

Section 2: Baby Boomer Questions (Born 1946–1964)

- How has the evolution of farm equipment during your lifetime prepared you for drone technology?
- What influenced your decision to adopt or avoid drone technology?
- How does the cost of drones compare to past technologies like GPS or auto-steer?
- Have drones made a measurable difference in yields, labor savings, or efficiency?
- Where do you see drones having the greatest impact?
- Do you believe larger farms benefit more from drone technology?
- In what ways have co-ops or suppliers influenced your opinion?
- How do you finance technology upgrades like drones?
- How are market conditions affecting your willingness to invest?
- What are the biggest barriers you have encountered?
- How do you think drones will affect long-term sustainability?
- What advice would you give other farmers in your generation?

Section 3: Generation X Questions (Born 1965–1980)

- How did you first learn about the economic opportunities of drones?
- What trends led you to consider drones as an investment?
- How have drones impacted operational efficiency?
- Do drone-derived data contribute to profitability?
- Have drones reduced labor or operational costs?
- How do drones help manage market or environmental changes?
- How do you calculate profitability compared to traditional methods?
- What farm size benefits most economically?
- Are drones used mainly to cut costs or increase revenue?
- What payback period have you observed?
- Have drones changed your market engagement?
- What challenges have you faced?

Section 4: Millennial Questions (Born 1981–1996)

- How did you initially become interested in drones?
- What influenced your decision to adopt them?

- What types of data do you collect and how do you use it?
- Which operations benefit most from drones?
- How do drones compare to other ag technologies?
- What were your biggest concerns before adoption?
- How have drones affected labor or farm practices?
- Do benefits differ by farm size?
- How do you stay updated on drone advancements?
- Have drones contributed to sustainability goals?
- Have you achieved financial returns?
- What advice would you give other farmers?

Section 5: Generation Z Questions (Born 1997–2012)

- How intuitive is drone technology for you to use?
- What creative ways have you used drones?
- Can you describe a time drones improved a decision?
- Which drone function is most useful?
- How have drones contributed to sustainability?
- Have drones influenced older generations on your farm?
- Do you collaborate with other young farmers?
- What challenges have you faced?
- How do you evaluate profitability?
- Do drones make farming more engaging?
- What role does online content play in learning?
- Is affordability a barrier?
- What future do you see for drone technology?
- What would make adoption easier?