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Original Research

Beef Cattle Producer Perspectives on Virtual Fencing ☆

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ABSTRACT

Virtual fencing (VF) is a rapidly expanding technology that uses global positioning technologies to send audible and electrical cues to livestock that create invisible boundaries to replace physical fencing. The technology portends several benefits, from replacing costly and hazardous physical fencing to being an additional tool to contain, exclude, or move livestock. While researchers and VF providers work to improve the technology and applications, little is known about producer perceptions of its capabilities and what they most want in a system. We conducted phone and in-person interviews with beef cattle producers to ask them about their views and experiences related to virtual fencing technology. We included producers that already use the technology (including producers currently installing the technology) and producers not actively considering or using the technology. Our findings identify benefits and barriers of VF from the cattle producers' perspective. These perspectives can guide new research, improve VF technology, guide educational programs, and help producers considering a VF system. Survey responses are organized into eight themes: animal stress and welfare; effectiveness, function, and technology; management impacts; financial and economic perspectives; improvements and advice; learning; privacy; and implementation. Producers who use the technology had greater optimism about the applications and economics and have found creative applications of VF specific to their operations. While they have more confidence in the technology, they still report issues such as collars falling off or base stations not working. Producers new to VF should expect a learning period both for themselves and their animals. Producers from all groups cite potential benefits from better use of forages, reduced wildlife conflicts, more flexibility and convenience, to the ability to better manage sensitive landscapes such as riparian areas or other areas affected by fire or drought.

Introduction

Fencing is critical infrastructure for livestock production, with many types, functions, and applications. However, traditional fencing is costly to install and maintain, can be hazardous to livestock and wildlife, and may limit where and how the land can be grazed. Thus, virtual fencing (VF) technologies are seeing a boom in adoption. Virtual fencing uses global positioning system (GPS) technology paired with collars (or sometimes ear tags) worn by livestock. This technological tool can enclose livestock within or exclude livestock from an area without physical fencing (permanent, e.g., "hard fence" such as five-strand barb wire, or temporary, e.g., electrical fencing). Virtual fence users (users) establish the placement of VF by drawing a line on the screen of a computer or personal device (e.g., tablet, smart phone), which reduces time and personnel needed to achieve management or production goals using fencing. When a collared animal approaches the VF, it receives an audio or electrical cue to deter it from crossing an established boundary (Anderson 2007; Umstatter 2011). Since the technology can be used to replace, complement, or supplement physical fencing, the potential applications are extensive. The technology offers opportunities for producers to increase profits by reducing installation, labor and maintenance costs of traditional fencing (Llewellyn et al. 2017), improve animal welfare and condition (Lee and Campbell 2021), foster varied grazing strategies

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(Horn and Isselstein 2022), protect natural resources and environmentally sensitive areas (Campbell et al. 2019, 2020), and reduce wildlife conflicts as wildlife can move around more freely (Jachowskiet al. 2014).

Virtual fencing technology was first tested on livestock in 1987 (Fayet al. 1989) but did not become commercially available until recently (Lipschitz 2019). As researchers investigated potential applications (Lomax et al. 2019; Kearton et al. 2019; Campbell et al. 2020), efficacy and design (Umstatter et al. 2015), and animal welfare and behavior (Lee and Campbell 2021), interest and adoption of VF rapidly accelerated. As new VF technologies become commercially available, questions remain about their utility and efficacy and the role they could play in modern livestock production. For example, some of these questions are: What attributes of the technology are attractive to early adopters? What concerns do producers have that would limit adoption? What types of operations benefit most from adoption?

Brier et al. (2020) surveyed VF experts in New Zealand in 2016. Twenty-five experts convened on at least three occasions to identify three important benefits: 1) improving protection of environmentally sensitive areas; 2) more efficient pasture allocation; and 3) facilitating grazing in areas where grazing was previously unavailable due to inadequate fencing. Labor savings and individual animal management were also mentioned. Technical factors were identified as the primary barrier, particularly regarding reliability. Concern was expressed about whether the system could pay for itself, public and ethical considerations, and excessive training needs. One participant expressed: "*Any new technology needs to be able to clearly articulate return on investment!! This is often the failing of new technologies in agriculture*" (Brier et al. 2020, p. 561). Their perception of future implementation included anticipating socio-ethical issues related to animal welfare; technological, political, industrial, and economic uncertainty; and the need to be inclusive with industry and the public. The researchers further found that producers would want nearly 100% efficacy before being willing to adopt; and acquiring necessary skills may be a significant hurdle.

While Brier et al. (2020) collected their data less than 10 years prior to the publication of this paper, there have been significant changes regarding VF since then. Specifically, the advancing technology has become more widely adopted, but still is not being used extensively, despite soaring costs for traditional fencing. In addition, their study was based on what *experts* thought about the technology. In contrast, our study explicitly set out to understand how practicing cattle producers perceive VF technology.

This study adds to the scientific literature of VF, highlights how VF is perceived and used by producers, and identifies several needs and wants of producers contemplating adoption of the technology. Knowing how producers perceive VF factors into the future adoption and success of VF in rangeland settings. Ultimately, the knowledge gained from our study can be used to design new research, modify existing VF technologies, guide extension and outreach programming, and help shape cost-share policies.

Methods

The focus of our study was extensive cattle operations in the western United States. Since the technology is not widely used, we drew our list of interviewees from researchers and extension specialists working in the region. Using the snowball method (Naderifar et al. 2017) to find potential participants, we started by contacting professionals to request our first wave of contacts. We followed up to request interviews, and then we asked those we interviewed to recommend other producers that we could interview. Using this approach, we secured interviews with 31 people in five states: Colorado, South Dakota, Montana, Washington, and Utah. We had no response or were turned down by 19 producers. We interviewed 15 producers using VF (hereafter referred to as "users")—eight had already installed VF and seven were in the process of installing it. All users adopted Vence systems, which at the time of interviews (2022) was the most widely used VF system in the United States. We also interviewed 16 producers who had not yet seriously considered installing a system (hereafter referred to as "nonusers"). We interviewed these two groups to determine if there were gaps in perceptions and interests from those with varying experience levels. Each interview was recorded and transcribed using asynchronous speech recognition in Google Docs, with personally identifiable information redacted.

Our procedures were approved by the Research Integrity and Compliance Review Office at Colorado State University (Proposal #3486). Qualitative, in-person or phone surveys were conducted with users and nonusers. We utilized these methods instead of mailed paper surveys, as response rates for mailed surveys are typically lower in comparison (Stedman et al. 2019). Also, we wanted to have a one-on-one conversation with each producer. Qualitative research involves collecting and analyzing non-numerical data to understand principles that are difficult to categorize and measure through quantitative research, which uses numerical and categorical data to reflect the views of a representative group (Gioia et al. 2013). Qualitative research is useful when a topic is difficult to clearly define. We focused on gaining a better understanding of how VF is viewed in terms meaningful to livestock producers (Gioia 2021).

Following best practice guidelines and recommendations for qualitative, semi-structured interviews (Weiss 1995; Charmaz 2006), our protocol included a script to guide our interactions with respondents. We also developed open-ended questions that were designed to ensure they fit participants' experiences as VF users and nonusers. The open-ended questions allowed for the materialization of unexpected observations and insights. Data collection took place between the months of August and October 2022. Interviews lasted between 60 and 75 min.

We devised two similar versions of the survey for each producer group: users and nonusers. Prior to interviews with producers, the questions were circulated to colleagues in extension and research roles at land-grant universities to review and were revised accordingly. Each survey had eight questions about VF, plus a demographic section describing livestock number and class, acres managed (private leased and deeded, and public grazing permits and leases), current fencing, ranch income, and location. The survey questions centered around the following themes (known if using VF, or perceived if not using VF):

(1) Why they chose to use VF, or if not using VF, their knowledge about VF
(2) Who influenced their choices
(3) Benefits of VF
(4) Challenges or risks associated with VF
(5) Cost, effectiveness, animal welfare, labor, management and environmental outcomes between traditional fencing and VF
(6) Future use of VF
(7) Advice on VF
(8) How to improve VF, or what they would like to see most if not using

Coding

Following Gioia et al. (2013), we first applied first-order codes to the text in each transcript. For example, a comment on collars would receive a code, which might then be divided into subcategories like cost, reliability, battery issues, or fit. All the authors reviewed a portion of the transcripts and developed codes for each

unique point that they found. Two of the authors reviewed all the transcripts. The second step was to aggregate first-order codes into second-order codes aggregated around themes, e.g., a theme might be codes related to costs, or codes related to reliability. Themes were based on discussion and agreement from all the authors, which had all participated in first-order coding. The third step was summarizing what survey participants reported about each theme, comparing responses across different interview groups, and making recommendations.

Results

Demographic information

Our sample is not representative of a producer population because the objective was to identify the depth of issues, not the proportion of producers that identify with a given issue. We interviewed producers whose cattle operations utilize private land or both private and public land. Public land included U.S. Forest Service, Bureau of Land Management, and state land leased to the respondent. Private land referred to any land owned by the respondent or leased from other private entities. The size of operations ranged from 500 acres to 140 000 acres. Cattle management ranged from 10 head to 5 000 head. Overall, users had larger operations in both acres and cattle numbers than nonusers. Where appropriate, we discuss how demographic factors affected results in the themes reported below.

Coding themes

First-order coding resulted in 45 categories and more subcategories, totaling 264 codes. First-order codes were grouped into eight themes (Table 1): animal stress and welfare; effectiveness; function and impact of the technology; management impacts (environmental, range, and animal), finances and economics; future improvements and advice; learning; privacy; and reasons for implementation.

Issues that producers raised more frequently likely indicate concerns that are important to the survey respondents. For example, several issues were cited at least 10 times. Users were more concerned about collars than nonusers. In comparison, nonusers were more concerned about breaches, and uncertain about technology and the cost of VF. The disproportionate concerns in these areas represent factors that might hinder adoption. Both producer groups felt that VF would contribute to grazing management, improve land stewardship, and help monitor livestock. They also agreed that VF could provide environmental benefits and help wildlife. Further, both groups felt that traditional fencing was expensive and required a lot of maintenance, but VF could offer adaptability and lower costs. More producers thought VF would decrease costs, but some thought costs would increase. Nonusers felt that operating costs would increase with VF, again highlighting an issue where uncertainty around a new technology hinders adoption.

We report on survey findings from each theme in the following sections.

Animal stress and welfare

This theme included impacts that VF technology could have on cattle stress and welfare. Users and nonusers in our survey mentioned this theme infrequently, but seven mentioned cattle stress and welfare. Many of the references to livestock stress and welfare concerned training the cattle, which overlapped with the learning theme (i.e., some consequences of the learning process could be impactful to stress and welfare, such as multiple electrical cues, and animals not understanding the reason for the cue).

Producers had variable concerns, positive and negative, about how VF can impact animal welfare. For example, one user said: *"it is a danger to the cattle because every time you bring a cow through a chute you have that possibility of getting somebody hurt or cattle hurt and we did end up losing a calf .. through all the stress;"* however, this producer mentioned improvement over time. Similarly, another said that sometimes human error (e.g., in collaring livestock or inappropriate fence management) can add stress to the system; it's not necessarily the VF technology itself. One user mentioned that after learning how to apply the system, they could manipulate their cows more naturally (with VFs rather than physical fences), a benefit in lowering stress and improving welfare. Several producers discussed benefits to wildlife, including reduced fencing injuries. For example, one producer felt that VF could offer cattle protection from predators, such as wolves and mountain lions, as there would be no physical fence on the landscape hindering escape from predators.

VF users had some questions about the overall impact on cattle stress and welfare, for example: *"Are these cattle going to gain as well, are they driving as well, are they loading as well, are they a little more nervous you know because they are just learning these collars what effect does that have on their grazing ability."* Another user stated having limited concern for animal welfare with VF implementation: *"From an animal welfare perspective I don't have a lot of concerns, I mean, I have been out there, and I have seen when these animals get a sound and a shock [electrical cue] and listen it is pretty darn mild."* This statement was also linked to the learning theme because the producer further commented: *"…they figure out right away that they don't want that shock [electrical cue] and they take active steps to avoid that happening again."* A nonuser shared the following when asked their opinion about welfare impacts of the VF technology:

> *"I think they would benefit from it. I mean I think the animals would do better when you force them to kind of get out of some places where they just tend to camp or can't be. I mean there are always spots where they're always kind of hanging out you know but if you can get them out you know grazing on different grounds, I don't think it will hurt them a bit."*

Effectiveness, function, and technology

Reliability was one of the most important factors for determining the willingness of nonusers to adopt VF. Specifically, nonusers wanted to know more about how VF can be effective and expressed concerns about what would happen if the system failed. One nonuser stated: *"I think it's a great idea in concept but, in reality, I don't know if it really would be functional just because, what if, what if it does go down and then you have to put up a physical fence?"* Producers ascribed different, but complementary strengths to VF and physical fencing. Both groups recognized that VFs are not reliable enough for ownership boundaries, where livestock escape would be consequential (e.g., along roads), and in areas where containment is operationally important like gathering areas. The inability of VF to exclude neighboring cattle or human trespassers was often cited as a reason for needing to maintain physical perimeter fence, particularly in fence-out states. One user noted that they are removing perimeter fence between their ranch and a neighboring ranch that also has VF. Users valued the flexibility and ease of establishing VF and mainly use VF as internal fencing.

Both producer groups saw value in the ability of VF to be used in adaptive management scenarios, such as in drought conditions. The fact that wildlife movement across the landscape

Table 1
Second order themes for livestock virtual fencing users, in process of implementing and nonusers.

Theme	Theme definition	Selected producer quotes
Animal Stress and Welfare	Reference to animal health including stress, health improvements, death, and ability for monitoring needs related to health.	*"It is a danger to the cattle because you are bringing, every time you bring a cow through a chute you have that possibility of getting somebody hurt or cattle hurt, and we did end up losing a calf through it through all the stress."*
Effectiveness, Function, and Technology	Fence effectiveness and function, both successes and challenges, including fence barrier effectiveness and accuracy, animals breaching boundaries (including respondent's animals and neighbor's animals), collar function (e.g., installation, batteries, weather issues, collar loss and durability), and signal function often related to usability in different terrain.	*"Right now, with the (collar) retention issue and batteries, I would have to call (virtual fence) 50% of a permanent barrier (physical fence)."*
Management Impacts	Management factors and impacts of virtual fencing specifically related to the environment or animal monitoring; this included impacts on grazing approach (e.g., rotational, high density, etc.), different vegetation types, and locating animals on the operation. This also included impacts on wildlife and forage production.	*"You could still manage to let an area recover without precluding another area from not grazing. That's important for the financial impact to the rancher."*
Financial and Economic Perceptions	Financial costs and benefits, including cost sharing of fence investment and opportunities for increased income (i.e., forage).	*"I've looked at it [VF] for several years and, if it could actually work the way they think it should, it could be a money and labor saver."*
Improvements and Advice	Virtual fencing technology that respondents hoped to see in the future, including an improved user interface, collar improvements with different animal tracking capabilities, water resistance, and other alert options. Also included advice for potential technology adopters including considerations for animal response, area of use and potential environmental challenges, and user technology skills.	*"User friendliness… making it user friendly"* *"An app on your phone…Helping you calculate and making management decisions on how frequently you should be moving cattle. …and… some sort of weather tracker,* i.e., *rainfall"* *"We use a multi species approach…small ruminants, goats, sheep"* *"I'm also interested in, … Predator management?*
Learning	Inclusion of comments related to learning the virtual fence interface both from a human and animal perspective.	*"Like always doing anything new, one of the biggest challenges is training cattle. You know it takes cattle time to get used to things and of course if you can train them in a more controlled environment, you'll have better success so that is probably one of the greater challenges. The other challenge is training yourself."*
Privacy	Questions regarding the use of data generated by the virtual fence systems by outside entities such as NGOs, state and federal agencies, and environmental groups (i.e., not the livestock owners).	*"I think most ranchers want privacy of where their animals are and what they're doing."* "*This is a technology with a lot of political motivation to get cattle off public land grazing permits.*"
Implementation	Reasons for adopting virtual fence technology such as the desire to experiment with a new technology, financial incentive given for installation, economic and financial benefits, and predator management.	*"So, at $4 or $5 a foot [for traditional fence], it becomes quite expensive to replace those fences… We can move fences anywhere we want [with VF]"*

Note: Quotations from participants are presented as given. Interpretation is left to the reader.

does not impact VF was important for many producers across groups. Virtual and physical fences are being overlapped in some places to increase effectiveness in important areas, extend fence life, and to reduce the need for physical fence maintenance. For example, users cite reductions in livestock escapes that occurred from traditional fencing when wildlife, falling trees, snow drifts, or recreationists compromised the fence.

The ability of the virtual boundaries to contain livestock was reported to be high (~95%) when the system is working smoothly. However, users identified factors that reduce VF efficacy. Effectiveness declines as pressures that push or lure livestock to cross boundaries increase. These include lures such as desirable forage (e.g., alfalfa or corn) or water, or pushes such as predators. Several users found that livestock escaped virtual boundaries during storms. Calves are not collared (note: none of the existing VF companies recommend collaring calves due to their growth and potential for collars to become too tight) and may freely cross VF boundaries, putting pressure on a collared cow to follow their calf. Some users discussed reduced effectiveness of VF for containing bulls, although one respondent had success with bulls. Another user found VF to be ineffective at managing grazing on smaller acreages. They cited issues arising from limitations with the spatial accuracy of the system and challenges with battery life in small acreage pastures, as animals in these pastures encounter the auditory and electrical cue boundary more frequently. Cows were receiving auditory and electrical cues inconsistently—some cows in the same area were receiving cues while others were not. Another consideration that can limit VF effectiveness is the observation of cows moving forward when they experience the electrical cue, which can push them across VF boundaries.

Heavily treed areas or extreme topography can create gaps in base station or GPS coverage, compromising effectiveness. Users mentioned that they have learned to take these factors into consideration to design more effective VFs, with one user reporting a much lower livestock escape rate the second year of using the system, as the user became more mindful of where to place the VF. It was noted that poorly placed VF locations can even untrain cows (e.g., the fences are moved in unpredictable ways).

While most of the conversations about effectiveness were focused on containment, users have used VF to exclude, gather, and move cattle by excluding cattle from sensitive sites such as riparian areas, created "lanes" with VF to assist ranchers with driving cattle, and herded cattle through passively capturing them in successive pastures. Several respondents discussed how valuable the location data provided by the collars has been for finding animals, particularly during traditional cow-calf production timelines of artificial insemination in the summer, weaning in the fall, and coming off public land grazing permits and leases in the fall.

Views on the effectiveness of VF varied among producer groups, with users who recently adopted the technology reporting the most challenges. One recent adopter of VF was having issues with collars not updating regularly and was receiving outdated/unreliable location data for their animals. Users also highlighted challenges with figuring out how to put collars on

animals. Fitting collars correctly can reduce the number of collars that fall off; however, correctly fitting a collar can be cumbersome and time-consuming because the animal's position during installation affects the fit. Producers said they became more efficient and skilled at fitting collars over time. One user emphasized the importance of having a hydraulic shoot with a neck extender or another device to stabilize the animals' head and neck, allowing for safe collar installation for both the cattle and workers. Several users had issues with collars not able to provide an electrical cue due to the collar flipping; however, this issue has been addressed with updated collar designs (in reference to the Vence system).

Two other challenges with collars were collar retention (collars falling off) and battery life. *"Right now, with the (collar) retention issue and batteries, I would have to call (virtual fence) 50% (as effective as) of a permanent barrier (physical fence)."* One user experienced 25% of collars falling off within 5 weeks of installation. Estimates of battery life among users ranged from 3 months to $>$ 1 year, with users generally planning to use two batteries yearly. Extended battery life was mentioned as an area for improvement in the technology by both producer groups. One nonuser noted that their standard operating procedure is to handle and work cattle once per year, so the requirement for additional handling to replace batteries would make the technology infeasible for many operations.

Two users shared scenarios of base station failure. One producer had a base station lose service until it was updated when cellular service in the area changed to 5G Another producer had poor cell service negatively influence the VF system functioning. Both users and nonusers mentioned rugged topography as a concern for limiting base station signal coverage. Some users have been operating their VF systems in rough terrain and have learned to design fences that are minimally impacted by coverage gaps caused by topography, highlighting the ability of users to learn and adapt to the technology. Topography can also be an asset in base station placement when higher elevation locations can be used to achieve greater signal coverage. Internet service is also essential for accessing the website to manage the VF system where producers create the virtual fences. As a result, two users noted that they needed to upgrade their internet service to access the system reliably from their office. Overall, users said there is less maintenance on VF systems compared to physical fences; however, upkeep is still required in several forms: putting on collars, pushing animals back into the VF that have escaped virtual boundaries, finding collars that have fallen off or broken and re-installing them, changing batteries, and setting up VF boundaries.

Management impacts

The management theme included aspects of how VF relates to the environment, animal management and monitoring. Respondents to the survey heavily supported these concepts. Specifically, responses included under this theme were coded to include grazing approaches (e.g., rotational, high density, etc.), what the dominant vegetation is on the operation, and how animals are located. Wildlife and forage production were also coded and grouped under this theme. Many interviewees (18 of the 31) manage their cattle on native rangelands, while others utilize cultivated lands.

Fourteen of the 31 interviewees indicated they felt VF would improve their management. Of note, three users indicated that VF has improved their land management. One user said under a forest fire situation, *"You could still manage to let an area recover without precluding another area from not grazing. That's important for the financial impact to the rancher."* This allows land managers to utilize cattle as a *"tool…to improve resiliency on a landscape basis."* Some users felt that overall management would improve; two nonusers thought VF would improve overall management of their operation, while four nonusers specifically mentioned land management and two nonusers said animal management would improve. The intersection of land management and animal management was discussed by one producer who stated.

> *"There are certain places I would like to graze at a higher density for shorter periods, but it's difficult to cross fence, just because of the cost, and the time and labor to cross fence. So, if you could graze those areas to affect the vegetation in those areas…I do rotational graze anyways, but even in the paddocks I have, I would like to focus on areas even more intensely…it is hard to continually cross fence."*

Several benefits of VF were identified. The user group indicated that VF benefited them through rotational grazing (indicated by four users), grazing practices overall (indicated by two users), or increases in forage production from both rotational grazing and allowing pastures to rest. Some users also identified improved wildlife habitat as a benefit (likely due to lack of traditional fences breaking up the landscape). One of these users said:

> *"There are a couple three to four hundred head of elk on the property, and couple hundred pronghorn antelope. You know, regular hard-wire fencing is something that doesn't work very good. Plus, we've got about 50 head of bison on the property. So, we've got a lot of different animals that are on the property that tend to wipe out fences from time to time and so being able to keep cattle where we want them is kind of a continual battle. And with the [VF] collars, it doesn't matter, they can't wipe out virtual fence."*

Finally, some users mentioned that installing VF helped them know the location of cattle on their operation. Eight nonusers specifically stated VF would benefit rotational grazing, while three nonusers said overall grazing practices would benefit from VF.

Financial and economic perceptions

The cost of traditional fencing was mentioned as a problem over 40 times, and evenly across the two producer groups. Beliefs about the cost of VF were less decisive. For users, cost was mentioned as a "pro" twice as many times as it was mentioned as a "con," but the reverse was true for nonusers. Users were overall positive about the cost of VF compared to physical fencing. For example, one producer said that the cost of base stations can be amortized over multiple years and that the cost of VF saves him the cost of "*two cowboys*" every year—cowboys that are getting hard to find. The need for more information about costs was mentioned several times by both producer groups. Four users specifically mentioned that they received cost-share for their systems, which at the time of this study is not common as it is not incorporated into the cost-share practices approved by the Natural Resources Conservation Service (NRCS) for programs such as the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP).

Other factors that affected the cost of VF compared to a physical fence are labor, maintenance, useful life of the fence, and time required for upkeep. One producer in each group mentioned that VF was a benefit due to a longer lifespan. Maintenance was also mentioned as a benefit by both groups, but relatively more by nonusers. Both groups were optimistic about labor savings. One user said that VF saves him three weeks of labor usually applied to moving electric fences to graze crop residues. Another user said, "*in 4 h I can build an entire season worth of fencing on the computer*." The same producer commented that working in the office for 4 h was a "*heck of a lot more fun than one person driving around in a pickup all day to repair fences*." A few producers stated they used the saved labor more productively, like monitoring animal health. Users noted several times that there were disadvantages with VF related to collars, which will also affect costs. This was

not an issue identified by nonusers, possibly due to a lack of familiarity with issues.

Users were relatively more optimistic about the potential economic benefits that VF could accrue and discussed components that were easy and difficult to monetize. The primary benefit mentioned was that VF could give them the management tool needed to produce more feed, especially through rotational grazing. One producer commented that he could, *"pick up at least 25% efficiency and we rotate these cattle more effectively… it's probably more like 50 or 75%."* Yet another producer said that he could, *"take a 3000-acre pasture and divide it into 20 or 30 or 40″* smaller pastures. The economic benefits included improved weight gain and grazing conditions through targeted grazing, where producers have more control over both when and where cattle graze. users also noted several benefits that they found hard to monetize. For example, VF can facilitate wildlife movements and reduce mortality related to entanglements. It is easier for cattle to escape predators, and the ability to remotely monitor cattle movement can lead to quicker responses to downed cattle, and potentially make it easier to collect compensation related to predation. It can also reduce recreation-related problems, such as hikers not closing gates. Most users noted a need to maintain some physical fencing, but one noted that placing a VF in front of his physical fence greatly reduced damaged fences, especially from bulls, and extended the fence's life. One feature mentioned in multiple ways was the flexibility provided by VF. Some producers noted its value in exclusionary fencing that would allow greater ability to use sensitive areas, and another mentioned how he used VF to enhance herding.

Improvements and advice

The producers provided many suggestions for improvements to the virtual fencing technology. Feedback from users was based on their own experience using or learning about the technology, respectively, whereas nonusers shared the improvements that they would like to see incorporated before they would adopt the technology. In addition, users shared advice they would give to potential adopters. There were 52 recommendations for features. Interestingly, when asked how to make VF technology either more or less compatible with their own operations, all but one nonuser thought that VF might not be compatible with their operation's physical set up or current management goals.

An additional feature that interviewees mentioned was an improved user interface (UI). The UI serves as the bridge between the VF user and the VF technology system and serves as the mechanism through which the user communicates with the system. As one producer explained, "*User friendliness in any technology seems to be the differentiator between people adopting it or not. So, making it user friendly is important."* A poorly designed UI can lead people to abandon the technology or decide against adopting it in the first place if it is difficult or slow to navigate, requires substantial new skills or knowledge, or offers limited features. Several interviewees indicated dissatisfaction with the existing UI, but recognized that it will improve over time and offered relevant advice about being patient and not expecting too much. For example, one producer stated, "*Have somebody that is willing to be computer savvy and to be patient. Be reasonable [] in your animal husbandry and be patient in what your expectations are."*

One of the features several producers mentioned as hoping to see in the future was a smart phone app. For example, a user shared, "*I'm hoping (they) will come out with an app on your phone. They do it with the dogs. Once they get where you can use an iPad or your phone it'll be wonderful."* As technology becomes more prevalent in farming and ranching, it could offer new opportunities and employment niches for tech-savvy people, possibly with large operations employing their own technology staff and smaller operations using consultants. This is evident through one producer:

> *"We're always looking for: How can I make that margin a little bigger? So, I'd love to think that the potential is there for ranchers to hire somebody to help them with the tech side of the ranch. I think that on large-scale operations it could be. You know I think it probably is (profitable) on a very large-scale operation. For the average, medium to small-scale outfit, it's probably not."*

Another user added a related comment about how well-suited VF technology is for smaller operations. They suggested that a UI more attuned to this potential set of users would be a valuable new feature, "*I would say (expand) to smaller acreage, smaller animals. Like an introductory level (for smaller businesses)."*

Producers across groups also recognized that the technology would be more useful if it could provide additional information and alerts about the herd, related to animal management issues. Producers mentioned features like grazing tracking, health monitoring, movement reports, and predator alerts were mentioned. However, one producer laid out a convincing case that in addition to information, the most useful future features should integrate this information with decision rules to simplify herd management decisions for users:

> *"Having integration of multiple not just boundaries but also some sort of calendar system or calculator that can help you determine the number of animals or number of pounds you're grazing per acre. Helping you calculate and making management decisions on how frequently you should be moving cattle. As well as maybe even some sort of weather tracker,* e.g.*, rainfall or moisture tracker, built in so you can keep track of how recently or how long it's been since you had moisture. So, integrating different things like that, different tools, into a program or an app to help you look at different factors to make management decisions might be worthwhile."*

The suggestions for collar improvements also included different animal tracing capabilities and collar features like water resistance. Over time, VF collars have become more sophisticated and lighter weight. However, some users noted inconsistencies with the operation of different models leased in different years and recommended having consistently reliable collars. For example, one user stated, *"With some of what we're seeing right now, potentially the issue with moisture in the collars and not reading or being able to communicate. We didn't have this problem last year . . . that's for more investigation. What was different last year?"*

Collar compatibility with different animal classes was frequently mentioned. One nonuser noted, *"My understanding is that the collars only go on yearlings or mature cattle. So, baby calves, I don't think they've got collars for those yet. I'm still trying to figure out how that might work if you've got calves that can go explore but the cows can only stay on one side. How's all that [] going to fall into place?"* Another who grazes more than one livestock species notes, "*We use a multi-species approach and I know right now Vence is only for cattle, but as we add ruminants, goats, sheep, that becomes an option."* Users advised that new VF users begin with collaring young cows, so the producers themselves become accustomed to the VF collars and system, and also pay attention to the collars and not just place them and forget them.

Finally, producers provided a smattering of advice for potential technology adopters, including accommodating special circumstances. This included considering how well the technology fits with the operation's potentially unique features such as wildlife corridors, contiguity with designated wilderness areas, and cooperation with hunting outfitters. If these unique features are

a concern, VF technology could align well with or hinder them depending on the circumstances. Unique aspects of operations that respondents mentioned as potentially limiting the prospects of VF for their operations included managing grazing across noncontiguous pastures and custom grazing enterprises where the cattle being grazed are managed by someone other than the landowner and are typically only on the operation for the grazing season.

Learning

Producers did not mention learning frequently, but one-half of all respondents ($n = 15$) addressed this theme during their response to at least one interview question. Several discussed aspects of learning across multiple questions. This theme encompassed both the human operator and animal learning of the virtual fence interface. Producers from both groups mentioned the challenges that both people and cattle have for learning VF, but considered it manageable. They mentioned learning in response to the question "what have been (or what do you think have been) your greatest challenges or risks from using virtual fencing." For example: "*The greatest challenge is technology – learning it, learning the program*," *and "there are parts of it you have to learn,"* and "*a big learning curve because you're not educating just yourself you are educating everyone that works for you*." One user indicated that it is more than simply learning how to use the software. Rather, it's learning how to apply the technology to maximize advantages to the operation:

> *"We didn't realize that the challenge is not to install a virtual fence on your computer, your challenge is to understand how to use the virtual fence to the advantage of your animals and the land – that's the challenge. And once you start to think about it like that, you start to recognize all of the different things you can do by simply guiding your cattle to the right spot at the right time. And so, what that has really turned into I think is that the challenge to the rancher as I see it in the future is understanding the back end of the system."*

In the context of animal learning, most producers mentioned the need to train the cattle to use the system. Again, similar to references to people learning the system, most mentions simply stated that learning is a part of the process, not an insurmountable challenge. Many noted how the process improves with time and familiarity. One producer stated, "*It is a training thing, you have to train these cattle. So, you know next year my cows will be less hard, you know it will be easier to maintain it because they will have been there,*" and another mentioned, *"Like always doing anything new one of the biggest challenges is training cattle. You know it takes cattle time to get used to things and of course if you can train them in a more controlled environment you'll have better success so that is probably one of the greater challenges."* One interviewee identified learning as a shared experience between the user and the animal: "*Just like anything it takes a lot longer the first time you run your animals through the chute and both you and the animals are trying to understand how this is working and so forth."* An important point noted by one producer is that training is needed for physical fencing as well: *"I mean it is sort of like we train our cows to them. I mean they don't really respect a temporary fence [*i.e.*, electric fence] until they learn that it is hot you know and then they will respect it."* One nonuser questioned if the learning process would impact an animal's future response to being in certain grazing areas due to previous training experience: *"With a virtual fence would it limit the cows' range because if she was getting shocked in one place for a period of time and now you are like oh, I want my cows to go over there but now you can't move her because she doesn't want to go over there."*

Privacy

Data privacy was mentioned explicitly by one of the producers, who saw both the potential benefits and risks. This producer explicitly stated:

> "*I now have data on where my cows are, and that can be used for good or it can be used for bad. I think most ranchers want privacy of where their animals are and what they're doing. So, the privacy side really needs to be thought through and the privacy needs to remain with the rancher. The data is important to show that you've done the right thing, at the end of the day, but privacy of data is a big, big deal*."

Two nonusers did not explicitly mention privacy but raised concerns about government access to their data and usage to monitor their livestock. As one stated, "*This is a technology with a lot of political motivation to get cattle off public land grazing permits.*" They worried that federal agencies could mandate the use of VF, increasing the cost of federal grazing leases and limiting producer autonomy in making decisions to adapt to dynamic range conditions.

Implementation

The implementation theme encompassed why producers adopted VF technology, which included the responses of experimentation, financial incentives, economic and financial benefits, and predator management. Entities (e.g., university, friends, government organizations) that influenced adoption were also included under this theme. Our interviews revealed information about user perceptions and rationales that could only be speculated by researchers. For example, we interviewed three users who said that they are using VF technology as an experiment on their operation. For instance, one user said, *"…likes to try things and see if it works for the ranchers, and that's what we're doing…that's kind of what we're in it for, to see if it works for the ranching community."* The entities that influenced VF implementation for the users included universities and government agencies, while one producer stated a VF company representative influenced them. Several users stated that they were positively influenced by watching a demonstration of the VF technology. Others said their main reason for implementation was to be able to know where animals are on the landscape, but also to improve grazing management. Overall, users indicated that VF technology is superior in regard to reduced cost in the long-term; less maintenance; increased ease of wildlife movement, and fewer wildlife-fence conflicts and fence damage. One user expressed several advantages to installing VF:

> *"I know the technology with dogs and stuff…I know electric fences work. We haven't made them work around here because it doesn't seem like we can get by with wildlife – wildlife are really hard on electric fences. So, at $4 or $5 a foot [for physical fence], it becomes quite expensive to replace those fences on the mountain…so that was one economic driver why we're thinking about it…the fences are permanent where they're at – I'm not sure it always works the best for the range…We can move fences anywhere we want [with VF]…To get rid of all interior fences, I wouldn't have them ping but once a day, but to know the location of our cows quite regularly…we run in some pretty rough country…if we could put a [VF] fence behind us and keep things pushing…I can see it doing some good there…and the grazing improvement program in the USDA, they think it's a good idea, I guess. They're letting me use some of my grazing improvement money…so it won't be a big investment out of pocket for me. I've stayed in my old cowboy ways a long time, and I think this is the new thing for fencing…to see if it will work, I'm kind of excited for."*

While predators such as wolves, coyotes, and bears are front of mind for many producers, only one user indicated that predators were a reason for implementation. Specifically, *"I love my cows you know, and it is so hard to think about just feeding them you [] know to predators, it is very hard, and it is very stressful for those of us that feel that way like people don't understand it, but you know we love our cows."* VF technology can be used to exclude cattle from known predator areas and can also be used to locate injured or dead animals because of predators, allowing for better documentation for livestock indemnity programs.

Discussion

Research about VF use and merits has largely focused on controlled experiments that examine only one or a few dimensions at a time. For example, Horn and Isselstein (2022) looked at how to improve grazing management, Campbell et al. (2020) discussed how to protect sensitive environments, and Jachowski et al. (2014) examined how to reduce conflicts with wildlife. Waterhouse (2023), Campbell et al. (2018) and Lee et al. (2009) studied how effectively cattle learn to understand their boundaries, and Lee and Campbell (2021) examined cattle stress and welfare. The research experts surveyed by Brier et al. (2020) identified three expected benefits: protection of environmentally sensitive areas, better pasture allocation, and new grazing opportunities. That study predicted that aspects of the technology, especially related to reliability, would be the major barrier related to wider use among livestock producers. They also identified the importance of economic feasibility in adoption and predicted that new issues such as animal welfare would arise. However, we could not identify a previous study that examined how producers view the technology.

This study focused on producers rather than advisors and researchers. Our results largely support the findings in Brier et al. (2020), but we provided additional insight on specific aspects important to the literature, especially between users and nonusers. Our interviews with both producer groups, users and nonusers, revealed that producers see great potential for VF to be a valuable tool in livestock management. However, there was a lack of consensus about how the cost of VF compared to traditional perimeter fencing. Half of users perceived VF as less costly and vice versa for nonusers. The cost of a traditional barbed wire fence varies widely based on the location, remoteness and terrain, reaching $15 000–$20 000/mile or more (Kientzy and Milhollin 2024; Sahs 2022). Virtual fencing offers a potentially less expensive alternative (Hoag et al. 2024) that also provides unique management opportunities such as livestock tracking and flexible fencing for rotational grazing or herd management. The infrastructure condition, terrain, business model, recent events (e.g., wildfire), property size and more all factor into whether VF is economical relative to physical fence for a particular livestock operation.

Both groups agreed that this technology could be used effectively for targeted grazing, tracking animals, predator management, and exclusion from sensitive areas. Adoption of VF can improve management through better monitoring of livestock on the landscape and creates new opportunities for grazing where greater grazing control, flexibility, and precision is needed. Producers are naturally innovative, and the users we interviewed were eager and willing to find new applications beyond the ones stated above. Producers considering adopting VF can expect a steep learning curve for themselves and their livestock. VF users recommended that new users develop an implementation plan that fits the technology to their unique grazing environments and management style (e.g., putting VF fences when and where needed).

Our survey found persistent concerns about boundary breaches, collar function, and durability. Nonusers specifically expressed concerns about the applicability of VF to their operations, including direct comments made about system reliability. Nonusers were largely concerned about costs and reliability, while users were more comfortable with those elements, as they were able to overcome them with experience. Both groups shared concerns about topography affecting reliability and offered various opinions about how the technology could be used for adaptive management when facing drought or wildlife conflicts, and to monitor and control livestock behavior. While many felt the technology was not yet ready for perimeter fencing, it was seen as valuable for internal fencing, improved land management, rotational grazing, herd management, reduced wildlife conflict, and location monitoring.

When asked what advice users would offer new adopters, they cited an improved interface, possibly on a cell phone, access to someone knowledgeable in information technology, and careful consideration of how well VF fits their operations and management needs. They also offered ideas about how they would like to see the technology improve. Producers would like to see VF technology provide alerts, track grazing and monitor health. Possibly, VF could be linked to sophisticated decision aids, like remote sensing.

Animal welfare and behavioral considerations have become increasingly important in recent years, and VF technology has been linked to these concerns (Stampa et al. 2020; Lee and Campbell 2021). Producers in our survey were generally not concerned about VF technology negatively impacting animal welfare, except for some stress when cattle were first learning about VF boundaries, during additional animal handling for collaring, or dangers related to collars during animal handling. In fact, several producers felt that VF could offer animal welfare benefits like protection from predators since they had fewer boundaries hindering escape. Producers indicated other positive animal welfare-related benefits such as stress management, access to higher-quality feed, and health and movement monitoring. Impacts of VF on animal behavior and implications for management, such as how long cattle avoid previous virtual fencelines (e.g., Umstatter et al. 2015), were an area of active learning for VF users.

Implications

As VF technology rapidly improves and if the cost of physical fencing continues to soar, we anticipate that the use of VF will grow. As implementation increases, the technology and its uses are quickly evolving. This can add confusion and uncertainty to designers, users, and advisors alike. Our survey demonstrates that VF users express less concern with reliability and uncertainty than nonusers, which identifies a need for more education and discussion of field results and portends an acceleration of adoption over time. VF users express the need for improvements to the technology, especially for collars, batteries, and the user interface, but report that they have learned how to use the technology effectively despite limitations; and they are continually innovating. Improvements in the cost and performance of the technology, expanding uses and higher traditional fence costs will drive this technology forward.

Over time, we expect that industry will add some of the improvements mentioned in this study, such as a better interface and decision support tools that can optimize grazing and other management objectives. While VF users are already finding value, there is much uncertainty about what the technology can provide, what it costs, and how it will change. Perhaps this amount of uncertainty is too much for many producers; but information is rapidly being discovered and shared for those still "on the fence" about adoption.

Declaration of Competing Interest

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

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Supplementary materials

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