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"There will always be collars in my future"; Exploring US ranchers' and company representatives' perspectives of virtual fencing for livestock

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ABSTRACT

Fencing is essential for rotational grazing, a pivotal practice to support conservation and natural resource management. Virtual fencing offers a technological alternative to traditional fencing and represents potential for increased resource optimization in rotational grazing. While the virtual fencing industry is emerging in the US, adoption is still limited and research on its benefits and broader implications is still minimal. This exploratory study examined the potential and limitations of virtual fencing products and assessed the conditions that enable ranchers in the Midwest to reap the most benefits from their use in grazing livestock. We conducted qualitative interviews with company representatives bringing virtual fencing to the US market and ranchers piloting them on their livestock operations. Environmental benefits included facilitation of strategically-planned rotational grazing that improves pasture management. Economic benefits included significant savings in time, money, and labor for ranchers. Animal welfare was perceived as positively impacted, with the technology allowing detailed tracking of animal behavior and movement. Challenges included current market capacity to meet demand for virtual fencing products, the costs, and concerns about collar functionalities like GPS accuracy and battery life. The interaction of virtual fencing with existing fencing laws is also uncertain, representing uncharted territory. Overall, while virtual fencing shows promise in revolutionizing livestock management, its adoption is contingent on addressing these multifaceted challenges. The findings provide a roadmap for further investigations pertaining to the use of virtual fencing to facilitate natural resource management and conservation practices, specifically adaptive rotational grazing of livestock.

1. Introduction

Fencing is a crucial aspect of agriculture. It is essential for livestock management, crop protection, controlled grazing, property security, neighbor relations, legal compliance, and even wildlife management [1,2]. Different types of materials are used for fencing, ranging from wood and stone to barbed, woven, cable, mesh, high-tensile, and electric options. These diverse fencing products have been used to create a permanent or temporary boundary to control the movement of people, livestock, and wildlife. However, installing, repairing, preventing damages, and in general, maintaining fencing is labor intensive and its prices are high across the different materials.

Fencing is also essential for rotational grazing, the practice of intentionally rotating livestock through multiple fenced paddocks with repeated periods of grazing and rest [3–5]. Recently, there is increased attention on rotational grazing from policymakers, conservationists, and extension services as a natural resource management tool. When well-managed, this type of grazing system enables the recovery and regeneration of pastures between grazing periods and provides soil health improvement [6,7]. Rotational grazing is also used to manage undesired plant species, clear dense underbrush, and to create firebreaks to reduce fire loads in overgrown environments [8–10].

Rotational grazing requires multiple paddocks for livestock rotation—the duration animals spend in each paddock can range from 12 hours to two weeks, depending on the pasture's condition—with rotations determined by plant growth and stocking density instead of a fixed schedule [11]. Of course, building several paddocks with physical infrastructure for fencing can require high fencing expenses, posing a

Abbreviations: GPS, Global Positioning System (GPS); USDA, United States Department of Agriculture; EQIP, Environmental Quality Incentives Program; CSP, Conservation Stewardship Program.

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significant financial challenge for ranchers. The labor involved in building and maintaining physical fence or moving portable electric fences to facilitate frequent rotations is cited as a major deterrent to adopting rotational grazing [12].

To reduce these challenges, a technology called "virtual fencing" has recently been introduced in the US. Virtual fencing offers a technological alternative to traditional fencing and represents potential for increased resource optimization in rotational grazing. This emerging technology allows the creation of virtual barriers or boundaries for animal containment and management. With virtual fencing, livestock such as cattle, sheep, and goats wear collars equipped with a Global Positioning System (GPS) that tracks their position and movements [13]. This tracking is linked to software that can be accessed on a mobile application and/or cloud management platform where a farmer can see where their animals are using a smart phone, tablet, or computer, while using those devices to designate non-physical boundaries directing animal movement. When animals approach the boundary, they encounter an auditory stimulus that intensifies as the animal gets closer to the limit. This signal provides a warning to the animal that they are approaching the edge of their boundary and should go no further. When the animal reaches the boundary, it receives an electrical pulse that is less intense than that of an electric fence [14]. In sum, this technology is supposed to facilitate a farmer's control over the trajectory and rate of their animals' movements and create easily changeable boundaries.

The idea of virtual or invisible fencing is not new. In the 1970s and 1980s, the first patents for devices to control the movement of animals using various mechanisms began to emerge —the initial patent for a commercial virtual fencing system, designed for domestic dog control, was issued in 1973 [15]. In 1987, a prototype of virtual fencing was trialed for the first time in livestock management [14]. The initial device incorporated a signal-emitting wire placed around the area and a receiving wire attached to the animal. Subsequently, newer devices were developed and expanded in sophistication, testing ear tags, collars, and radio frequency transmission [15]. It has taken several years for these various experiments to evolve into commercial products that can be utilized for livestock management.

Today, a handful of companies have been piloting their collar devices in farm trials and entering the market. In the US market, currently there are four companies commercially offering virtual fencing solutions —Nofence, Vence, eSheperd and Corral Technologies. Nofence was founded in 2011 in Norway and is currently available in United States, the United Kingdom, Ireland, and Spain [16]. Vence is a New Zealand company that was acquired in 2022 by Merck & Co and currently available in the US [17]. eSheperd was developed by the company Agersens, acquired by Gallager, a company from New Zealand created in 1928 and trailblazers of electric fencing [18]. Corral Technologies is a US-based startup developed in Nebraska by an entrepreneur and rancher and is starting to reach the market [19].

While the industry is emerging, adoption is still limited and research on its benefits and broader implications is still minimal. Virtual fencing is part of the broader process of agricultural digitalization, which integrates digital technologies such as sensors, data platforms, automation, and artificial intelligence aiming to optimize decision-making and enhance productivity in farming. Literature on digitalization raises overarching questions on the social, ethical, and environmental implications [20,21]tied to these technologies, including data ownership, accessibility, sharing and control, distribution of power impacts on human life and society. [20,21]

To date, a few studies have examined whether prototypes of virtual fencing are able to contain small samples of animals —including cattle [22–24], sheep [14,25–27], horses [28] and goats [29]. Some scholars have also explored its potential use in conservation settings with elephants [30,31] and bare-nosed wombats [32].

Past research focused on livestock such as cattle, goats, and sheep have assessed whether virtual fencing effectively controls livestock movement [22,23,26,33,34] and on how animal welfare is impacted by using virtual fencing systems [14,25,33,35–37]. Overall, these studies find virtual fencing to effectively enclose livestock and generally report neutral animal welfare implications, with no acute apparent negative impacts. That said, there may be some variation in terms of the stages of learning the virtual fencing system [26], and some inter-individual variations between different animal's personalities and their comfort in learning this new system [33]. One study suggested that the success of virtual fencing technology may be significantly influenced by the actions of lead animals within the herd that can influence other animals to move outside of the fencing [24]. Marini (2018) and Campbell (2019) each observed that sheep effectively learned and respected virutal fencing systems, although the latter study concluded that devices might only suit certain sheep breeds with less wool [14,26]. Finally, in the case of goats, another study identified that goats in commercial herds can adjust to and be contained by virtual fencing, yet there was considerable variation in the number of audio cues and electric stimuli both individually and between groups receive [29].

Research exploring ranchers and stakeholders' perceptions on virtual fencing in livestock systems reveals both opportunities and challenges across different countries and contexts. A study in Ireland explored stakeholders' perceptions, identifying virtual fencing as a way to reduce costs, improve efficiency, offer solutions for remote areas, and reduce labor demands [37]. However, concerns emerged about poor connectivity, animal welfare implications, and risks from the lack of a physical barrier, raising questions about impacts on wildlife, animals, and people. Similarly, research on cattle farming in New Zealand [38] highlighted skepticism among ranchers regarding the reliability of virtual fencing, inadequate return on investment, public concerns about animal welfare, and the need for significant training time to master the technology. Additionally, the study noted that that imprecise feed budgeting and grazing management limit the full potential of these systems, suggesting that without proper decision-making skills, the benefits of technologies like virtual fencing may not be fully realized. In Australia, a study explored virtual fencing through a responsible innovation lens, reporting that virtual fencing adoption requires support frameworks and deliberate integration of responsible innovation principles throughout product validation and implementation [39]. This approach ensures that virtual herding technologies are adopted responsibly and with the necessary safeguards. In the United States, the only study to date examined the perceptions of ranchers involved in extensive cattle operations in western states [40]. These scholars compared producers who use virtual fencing technology with those who do not, identifying key themes around animal welfare, technology reliability, financial costs, management impacts, and privacy. Across all contexts, the adoption of virtual fencing is shaped by a complex interplay of technological, economic, social, and ethical considerations, highlighting the need for comprehensive support frameworks to encourage responsible use.

To add to this body of knowledge, this study focuses on the Midwest US context and includes ranchers producing goats, sheep, or cattle with different farming size operations and participating in pilots with different companies. While virtual fencing is starting to become a commercial option in the US, there is still a significant gap in comprehending its wider applications and implications. The promise held by virtual fencing to make it easier for ranchers to adopt rotational grazing by decreasing the time, costs, and labor involved in managing physical fencing calls for a thorough exploration. It is important to discern how these possible benefits manifest in various contexts, pinpoint which ranchers are most suited for this technology, and to unveil the challenges and unintended consequences that may arise from its use. This exploratory study examined both the benefits and limitations of virtual fencing products and assessed the conditions under which ranchers in Midwest states can reap the most benefits from their use in grazing livestock. Ultimately, our goal is to deepen our understanding of technologies that contribute to advancing practices that support conservation and natural resource management in agriculture, highlighting both their advantages and the complexities they introduce.

2. Methods

This exploratory study investigated the potential and limitations of virtual fencing products and the conditions under which ranchers can benefit from their use in grazing livestock in the US, with a focus on products emerging on the market in Midwest states, including Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota and Wisconsin. Between March and November 2023, we used two strategies. First, we did a systematic review of websites and public information available for these companies and conducted a content analysis. Second, we conducted nine qualitative interviews with ranchers using these products within commercial pilot projects and with representatives from companies currently bringing virtual fencing to the US market.

2.1. Participants

We began by conducting web searches to identify companies advertising virtual livestock fencing products in the U.S. and consulted grazing experts to help identify companies for interviews. At the time of the interviews in early 2023, four companies were advertising virtual fencing products in the U.S. market.

We initially focused on recruiting companies piloting virtual fencing products in Midwest states. Through experts in the field and in each interview, we learned that virtual fencing products are in pilot phases in the Midwest states. We requested that company representatives connect us with producers in their pilot programs, applying a snowball sampling approach [41]. Of the four companies, three agreed to participate in interviews. Through these discussions, we confirmed that virtual fencing products were indeed in pilot phases across the Midwest and asked the companies to introduce us to ranchers using their products. We thus requested that each company put us in touch with ranchers in their pilot programs to identify a list of ranchers to recruit for participation in an interview. We contacted 11 producers involved in the pilot programs across five states and successfully identified six ranchers in three states who agreed to be interviewed. The participating ranchers had operations in Midwest states. Ranchers differed by what type of livestock they produced: either goats, sheep, or cattle. All ranchers have been testing virtual fencing devices for at least three months. Table 1 provides descriptions of their operations.

While the number of interviews may seem small, it reflects the nascency of this virtual fencing industry in the Midwest and small number of ranchers in pilot programs.

Table 1
Description of participants.

Participant	Description of farming operation
Rancher 1	• Raises 100-200 goats and sheep for meat and breeding • Runs contract custom grazing operation for weed and brush control
Rancher 2	• Raises 500-1000 goats for meat and breeding
Rancher 3	• Diversified crop (corn, soybean, hay) and livestock operation • Raises 100 cows and 80 goats
Rancher 4	• Raises 120 goats for meat • Runs contract custom grazing operation for weed and brush control
Rancher 5	• Diversified farm with turkeys, pigs, and small cattle herd • Runs contract custom grazing operation with cattle
Rancher 6	• Raises 1,200 cows in cow-calf operation, been doing rotational grazing since 2017
Company representative 1	• Virtual fencing technology company for cattle, sheep, and goats • Products have been commercially available in Europe for 3-6 years • Products in pilot phase in US states since 2022
Company representative 2	• Virtual fencing technology for cattle • Products in pilot phase in US states since 2022
Company representative 3	• Virtual fencing technology for cattle • Products in pilot phase in US states since 2022

2.2. Data collection

We collected data between March and November 2023. We conducted a systematic review and content analysis of virtual fencing company's websites and other publicly available information, including press releases and presentations at events. To identify companies, we conducted online searches on Google and Google Scholar using the following term combinations: virtual fencing; virtual fencing and livestock; virtual fencing and cattle; virtual fencing and sheep; virtual fencing and goats. We also identified companies through snowball sampling, asking experts in the field and at the end of each qualitative interview if they knew of other companies marketing these products in the United States. This combination of searches helped us to identify four companies. We reviewed and coded content from each companies' website at systematic timepoints, returning once a month between March and November 2023. We examined each company website, noting product features, company characteristics, and business models. Table 2 illustrates the coding categories we used for this content analysis.

Given the limited amount of information available on company websites, we also searched for news and press articles mentioning each company (using the company name and "virtual fencing) to gain insights into their market presence and level of development. We conducted these searches at one-month intervals in our content analysis.

We then developed interview protocols based on our review of academic and journalistic articles on virtual fencing in addition to input from grazing experts and the review of publicly available information about companies. The protocol for ranchers asked about how they learned about virtual fencing, their decision to get involved in a pilot program, and their experience using the product on their operation. The protocol for companies asked about their purpose for developing virtual fencing products, how their product works, their target audience for these products, and their perspective on the benefits and challenges to using virtual fencing for grazing.

We conducted semi-structured interviews with participants over Zoom. After obtaining consent from each participant, we recorded interviews using Zoom's recording function. Each interview was conducted by two research team members: one primarily asking questions and the other taking notes. Interviews lasted between 45-60 minutes. We continued conducting interviews until we determined that we had reached saturation: no new themes were emerging.

2.3. Data analysis

Data from the review of public information was analyzed through inductive content analysis [42] with a focus on product characteristics, type of producers targeted, current market readiness, and the overall benefits communicated regarding the use of virtual fencing.

Each interview recording was transcribed and identifying

Table 2
Coding categories.

Code category	Description
Platform type	Does the product use a web-based, mobile, or hybrid application?
Communication network	What type of connectivity is required? E.g. cellphone or a base station
Service model	What type of service model does the company used? E.g. subscription based, purchase or rent collars, purchase or rent base station
Collar characteristics	How do the collars work? E.g. what type of batteries
Type of livestock	What type of livestock does this product work for?
Market status	What is the status of the product in North America? E.g. available for purchase to the public, pilot stage

information, including names and locations, was removed from each transcript prior to analysis. We imported cleaned transcripts into NVivo 12 Pro by QSR International for analysis. Because this is a relatively new area of study, we used grounded theory to analyze data, employing inductive analysis to allow themes and patterns to emerge from the interviewee's own words [43].

Two team members conducted independent analyses of each transcript, identifying codes and writing annotations based on emergent themes. We then reviewed each set of codes and developed a combined codebook based on agreement of themes. We conducted a follow-up analysis to confirm that transcript excepts were appropriately coded based on the revised codebook.

2.4. Limitations

This exploratory study focused on ranchers and companies testing virtual fencing products in the Midwest, encompassing various livestock practices —goats, sheep, and cattle. While the sample size allowed for detailed insights into the perceptions of ranchers using this technology [44] the results may not be generalizable beyond the pilot projects. Future research could expand on this work by examining the evolution of virtual fencing and how ranchers in different environmental, regulatory, and farming contexts can leverage potential environmental benefits. Comparative studies across regions could offer valuable insights into the broader applicability of virtual fencing for rotational grazing and conservation.

3. Results

Here, we present findings from qualitative interviews conducted with Midwest ranchers participating in pilot projects using virtual fencing and representatives from companies piloting virtual fencing products in Midwest states. We start with a synopsis of the features of virtual fencing products and the current experience ranchers have using them. We follow with descriptions of the perceived benefits and challenges perceived by participants.

3.1. Features of virtual fencing products

This section combines insights from our content analyses of virtual fencing companies' websites and other publicly available information with data gathered through interviews with company representatives and ranchers. It presents the key features of virtual fencing technology, enriched by interview perspectives that provide context and practical insights. In general terms, all the virtual fencing products offer the main similar features. First, a mobile app where the rancher can draw paddock boundaries on their phone, tablet or computer and manage collars worn by the animals. Second, there are collars worn by the adult animals in the herd with solar-powered battery or with a non-rechargeable battery. The collars are equipped with GPS and Bluetooth for communications with the herd manager. The collars help facilitate grazing patterns through auditory and physical stimuli, effectively creating a one-way fence that normally constrains the animals into a defined grazing paddock but still enables animals to escape through the perimeter such as when driven by a predator. Notably, these systems allow the escaped animal to return to the herd without receiving a shock or hearing auditory signals.

The mobile apps that come with these fenceless systems are a key part of the technology, since they dramatically reduce the labor involved in creating paddocks. Simply by drawing on their phone, tablet or computer, the rancher can delineate the virtually fenced paddock and set up rotational moves between paddocks. One company representative described the process of using the mobile app to draw pastures and manage grazing pattern behavior (Table 3),

Table 3
Characteristics of Virtual Fencing Virtual Fencing companies' service model and target producers.

	Nofence	Corral	EGallaguer	Vence
Platform type	Mobile app and Web based	Mobile app and Web based	Mobile app and Web based	Mobile app and Web based
Communication network	Cellphone service	Cellphone service	Base station	Base station
Service model	Collar purchase plus subscription	Collar purchase plus subscription	Collar purchase plus a subscription and base station	Collar annual lease plus batteries and base station
Collar characteristics	Solar powered battery	Solar powered battery	Solar powered battery	Non-rechargeable battery
Livestock targeted	Cattle, sheep and goats	Cattle	Cattle	Cattle
Market status in December 2023	Finalizing pilots. Launching for public purchase in USA and Canada the spring of 2024	Pilot. Launching for public purchase in the fall of 2023	Pilot. Launching for public purchase in the spring of 2024	Pilots in operation

Source: Descriptions compiled based on interviews and publicly available information from each company

> *You essentially drop virtual fence post with your finger. You can have multiple pastures in your app, and then you assign collars, which are around individual animals to those paddocks. When an animal wearing a collar approaches the virtual boundary, the collar emits a scale of tones. It sounds like beep, beep, beep, beep, beep, beep, beep, beep. There's 8 tones that increase in pitch. And if they keep going, if they do not turn around to that sound, they then receive a gentle electrical pulse through the chain around their neck. If they keep going beyond that, it's because there is a stressor, let's say, there's a pack of coyotes or a neighbor's dog, or they're out of feed, and the incentive is great. In the case that they keep going, the collar is going to play that series of tones, followed by a shock 3 times, and then it's going to stop shocking for animal welfare concerns, and you're going to receive a notification that that animal has escaped (Company #1).*

3.1.1. Training for ranchers

All companies provide virtual training and support for ranchers in setting up the collars and using the mobile app to help them effectively use the virtual fencing system. Some aspects covered include training the animals, collar retention, and the relationship between collars and herd. On the animal training process, and in relation to animal welfare, the training programs are designed to help animals adapt to and comprehend the virtual fencing system. Companies also advise equipping only adult animals in a herd with a collar. Interviewees explained that although non-adult animals follow grazing patterns of the adults in a herd, adults possess the mental maturity required to grasp the cause-and-effect relationship between audio cues and subsequent consequences.

Collar retention on animals is a key aspect of functionality. The collar's effectiveness increases when it stays securely on the animal's neck, not falling off easily or frequently. On collar retention, two interviewees using different products pointed out the relevance of following properly the company's guidance. These quotes illustrate their experience.

One [mistake I made] was I didn't put the collars on tight enough. So, the animals were hearing the tones, but they weren't correlating them with the pulse from the collar (Rancher #1).

I think by day one we had, like, 30% of them fall off (…). We put them on too loose (Rancher #6).

3.1.2. Communication network

Companies rely on one of two types of communication network: collars connected to the mobile app through a cellphone network, or collars connected to base stations that must be set up by the rancher.

In the scenario involving a base station, the system captures cellular signals and converts them into lower-frequency radio signals to communicate with the collars. In the official website of one of the companies, base stations are described as solar powered and with coverage of 5,000-10,000 acres. A company representative stated that this approach ensures wide-ranging coverage in areas with variable cell service and is effective in properties needing multiple base stations for complete coverage.

In the case of cellphone network one company representative described the network requirements and what happens in areas where connectivity is low,

Our rule of thumb is that the virtual pasture should have at least one to 2 bars of cell service, like you should be able to send out a text, and then you'll be able to use our system. But if the cattle are in an area with low connectivity or a spotty dead zone, the actual original containment and the GPS still work. So, GPS works anywhere you're at around the world. The animals are still gonna receive an audible queue and a shock. You're just not going to receive a notification on your phone that the animal got shocked right there in real time. When the animal comes back in the service that data is logged and it will come flooding into your phone at that time (Company #1).

3.1.3. GPS, bluetooth, and battery

In both systems, the collars are equipped with Bluetooth technology, enabling ranchers to connect to the mobile application. This feature was described as particularly beneficial in situations where there is a disruption in the signal, or in instances where the collar is lost or becomes detached. "*You can play a little song on it, and it can help you find it*" described a one rancher in a pilot program.

Three of the companies provide batteries equipped with solar panels, which they said helped to ensure constant charging and reduces the need for frequent recharging. These solar panels work based on how much sun they get. The more they must shock animals nearing the boundary, the more power they use.

3.2. Potential and perceived benefits

All six ranchers interviewed expressed optimism about virtual fencing, intending to continue its use post-pilot. Their sentiments were encapsulated in statements like, "I think it's the future. It has a ton of potential" (Rancher #1), and "There will always be collars in my future" (Rancher # 2). Analysis of the interviews revealed three interrelated themes that underscore the motivations and advantages of adopting virtual fencing: environmental benefits, economic gains, and improvements in animal welfare.

3.2.1. Environmental benefits: potential for rotational grazing

Participants articulated interlinked environmental benefits from virtual fencing. First, the facilitation of rotational grazing in areas previously deemed inaccessible due to terrain challenges or lack of existing physical fencing infrastructure. Also, it has the flexibility to adapt to various landforms and needs, allowing for enclosure shapes beyond traditional geometric patterns. Second, the potential to improve how pastureland is managed through selective grazing to balance livestock nutritional needs with the maintenance and regenerative capacity of pastures. Two ranchers described these interlinked environmental benefits:

Physical fencing is very limited in terms of where you can graze. I could show you on the app right now. I've got goats that spent almost all of yesterday in a far corner of our property that I've never been able to graze before, because I couldn't get (to it). I had old fence lines that were 40 -50 years old, that are, you know, in the way. So you either gotta tear all that out, bury it, or graze around it (Rancher #3).

When you think that way [ambiguous shapes instead of hard lines], especially on the agricultural side there's a lot of advantages (..). It opens up a lot of possibilities that we never think about, because we always think in squares and rectangular, you know, but to be able to graze a small hilltop for 4 hours, because that needs really intense trampling and manure and urine, but we don't want them to eliminate all of the vegetative cover, and we want them to move on real quickly (Rancher #1).

3.2.2. Economic benefit: less time, less money, less labor

All the ranchers interviewed anticipated savings in time, money, and labor related to managing fencing infrastructure and animal movement. These savings result from the ability to strategically select grazing locations and durations, enhancing efficiency without necessitating additional investments in time, labor, or financial resources. Because they are still trying the product as part of a pilot endeavor, no rancher could provide definitive numbers. Some ranches offered preliminary estimates on the savings they expected from using virtual fencing. One of the ranchers with a large cattle operation estimated savings of USD 50,000 per year in labor:

We've got 1,200 females running on 13,000 acres of grass. If we wanted to implement true rotational grazing at the scale that we can theoretically with this technology, we would (normally) have to hire 2 more people on our team to do this. That's $100,000 in human expenses. I believe a full implementation with collars like this, we can do it by hiring one additional person. So that saves us $50,000 a year just in labor alone, and really that person that we would have to hire wouldn't be out moving around every day. They would be in my office or in their office setting up, they would largely be configuring grazing plans remotely on their computer (Rancher #6).

Another farmer was using virtual fencing to run a custom grazing business with their 120-goat herd. They explained the benefits that came from reduction of time and labor:

My customers are generally on side hills with very thick brush and setting up a temporary (electric fence) netting is the most difficult part of that job. My wife and I, we both work full time jobs already; grazing was supposed to be a part time hobby. But we found we were spending way too much time setting up fences on other properties just to do this business. So, when we became (aware) of the virtual fence idea, it become apparent to us that all of our time restraints would be eliminated if we did no longer had to set up physical fencing on these properties, we wouldn't no longer need be clearing fence lanes, setting up fence, all of that. So for us it was a time savings on our grazing jobs that convinced us that to try this (Rancher #4)

Another farmer running a large-scale meat goat operation of 500-1,000 goats, elaborated:

It's so much more than just the fence itself, the virtual fence, because you don't have to put up the fence. You don't have to own the fence. So, there's two huge price cost savings: the fencing itself, you don't buy it anymore; the labor to put it up, you don't have to do anymore; I can track them from my phone, I can see where the goats are at all the time, and I don't have to go and see them. I mean, I still farm and go to see my animals, but you wouldn't have to. You can see movements. I pull up my phone and just see things (Rancher #2)

The savings perceived by the interviewed producers facilitated the expansion of their activities, particularly because the virtual fencing technology allows them to utilize more available space without the need for large infrastructure investments that were required in the past. This represented a significant advantage, enabling producers to optimize the use of land more efficiently and economically.

3.2.3. Animal welfare: tracking data

Interviewees generally expressed a positive perception on the impact that this technology can have on the welfare of animals, attributing the benefits to its design and the continuous data collection. All ranchers highlighted that the ability to access tracking information about their animals, including their location and movement intensity, as a crucial benefit.

Ranchers described how the virtual fencing technology produced tracking information about animal behavior, which they described as useful for keeping track of where the animals are grazing and with what intensity. This information enables ranchers to see if an animal is away from the herd, a signal that may mean the animal is sick and needs help, or if any are lost. It also provides specific data to warn the farmer that something out of the ordinary is happening, like several animals escaping at once, which could be due to the animals fleeing a predator or being scared in some other way. Access to this information allows for closer and more consistent care of the animals' behavior patterns and needs. As described by two ranchers,

> *I can track them from my phone, I can see where the goats are at all the time. It could be the first thing you do in the morning. The last thing you do at night is make sure all the goats are in and doing their job, and everyone's healthy. If something stops moving, it'll notify you. If something gets out, it'll notify you. It gives you a whole added security (Rancher #2).*

> *One evening all of a sudden, my phone started giving me notifications that the goats were being warned and shocked. I mean several of them, which is highly weird and unusual. I picked up my phone right away and I looked at what was going on, and pretty much every animal in the herd had run towards the fence and was getting warned and shocked. And then, 5 min later it was done. I have no idea what the problem was, but I suspect that there they were, spooked by something. They were spooked, they ran, they hit the fence, they turn around, went back in, went to their safe spot, and whatever was out there decided not to pursue the issue and took off (Rancher #4).*

Another named benefit was affiliated with the one-way fence technology, which delivers an electric shock to animals only when they escape, not when they return, reducing the frequency of shocks received. One company representative indicated that the collars used have a constant voltage of 3 kilovolts, which is lower than the 4 to 10 kilovolts typically used in electric fences by most ranchers.

3.3. Identified challenges

Ranchers interviewed were generally optimistic about their experience in pilot programs and planned to keep using virtual fencing products. The general optimism that participants expressed on virtual fencing products was accompanied by acknowledgements of present challenges. The challenges discussed included the current market capacity, price and profitability aspects, functionalities of the collar, and some animal welfare and fencing law issues.

3.3.1. Market capacity to meet current demand

Ranchers were uncertain about whether companies are currently —or will soon be— able to generate the supply of collars needed to meet the demand. Company representatives stated that after their pilot phase, they will be able to scale up operations and provide collars to meet the increasing demand. However, given the US market's limited number of companies and their relatively short time marketing virtual fencing technologies, rancher interviewees felt it was still too early to determine the real, long-term impact of collar use on a large scale. This situation was emphasized by one large-scale cattle producer with an experience in pilots with 700 animals collared using two types of virtual fencing products,

> *We haven't had enough success with virtual fencing products yet to change our management strategy. Whether kind of maybe agnostic of brand, the technology is just new enough thus far that we haven't been able to say, all right, I've got 100 cows that have these collars on, and I'm going to rotationally graze them all season over here (Rancher #6).*

3.3.2. Price and profitability

For the interviewed ranchers, service cost was a pivotal concern. Pricing structures varied notably between companies. For example, one company offers cattle collars at $299 each, with an additional annual subscription of approximately $40 for orders exceeding 50 collars in a 12-month fixed contract. Conversely, another company opts for a leasing model, charging $35 to $55 per collar, plus the installation of base stations, each one with an average cost of $10,000. While the promise of virtual fencing is to ease livestock management and reduce the quantity of physical fences required, ranchers and company interviewees alike acknowledged that it doesn't eliminate the need for physical fences altogether. This was described by a rancher with a goat grazing business,

> *I have actually had to use physical fence as one side of my virtual fence boundary, simply because I absolutely needed to keep the goats out of a certain area and I just could not guarantee that with a virtual fence without putting the fence way far away (Rancher #4).*

Additionally, producers weighed the collar's purchase price, subscription fees, and in some cases the cost of infrastructure to secure connectivity. The combined expense of these three factors can be substantial, especially for those with large numbers of animals. Given the market's and technology's current level of maturity, ranchers lacked sufficient information to determine when and how they will see a return on their investment.

A rancher with a large herd and using base station pinpointed,

> *The downside is you have to purchase that infrastructure and that's $5,000-$10,000 per base station. That's another thing you have to manage right and make sure that they stay up and functional. They're not super portable. So, when I put that thing down, it's not easy for me to move into another place…So that kind is inefficient. But I still think it's probably superior to just straight up cellular financially and just effectiveness-wise (Rancher #6).*

Another rancher raising goats for meat and breeding and using a collar subscription service indicated,

> *You're looking at, it basically adds $70 to the cost of an animal every year. And you know, the offspring of a goat might only bring $150, and you haven't even accounted for feed costs and all the other costs that go into producing that animal. So, I just don't think it's there yet. I think that the cost needs to be cut in half almost for it to be viable agriculturally (Rancher #2).*

A rancher raising fewer than 200 animals also noted,

> *I don't think that you can be profitable raising meat, goats, or sheep for meat while using these collars currently at current prices (Rancher #1).*

It is not only a matter of price, but the model to bring the collars to ranchers. When asked for the service model that works better for him, a rancher emphatically indicated,

> *Rental, I don't want to buy them. (…) Here's the concern I have (..) I'll buy the collar next year. You're going to make improvements to it. Admittedly, you're gonna improve this model because this one is inferior.*

There are things that could be better. And I would really like access to those improvements (Rancher # 6)

3.3.3. Collar functionalities: GPS accuracy and Battery life

While ranchers generally valued that each collar has GPS, this feature is not completely accurate. For some ranchers, the combination of the imprecise nature of the GPS functioning, and the possibility of the collar not being visible in tall grass during certain seasons, could make it hard to find a collar that had fallen off an animal. Generally, all the interviewed producers expressed satisfaction with the collar's features and capabilities, but one rancher described this challenge with GPS coordinates when looking for a collar:

The problem is the GPS is not pinpointing accurately. So, if it's accurate to within 15 yards, that's a 45, a 90-foot circle. And I can tell you right now, if you and I were to drive out into a pasture with grass that's up to your waist, I don't care how close to accurate that GPS is you're not finding it…. Eventually that battery will die, and we will lose communication with it (…). This needs to be rethought… you're basically just wasting this product (Rancher # 6).

Although ranchers interviewed indicated that, in general, batteries work well, two ranchers anticipated potential issues linked to the weather. One emphasized, "*I think it's probably going to be more of an issue for us in the winter time with shorter and less solar intensity" Rancher r # 3*. Another rancher pointed out how issues arise both in summer and winter, and how in some cases, animal behavior can trigger more shocks and lead to rapid battery depletion. He described,

The batteries hold their charge for a long time. But I've run into some issues here in the summer when animals are seeking shade all the time. They'll eat what they need to eat, and then they'll go sit in the shade, and they're not collecting sunlight with the solar panels on the sides of the collars.

You would think in the winter it'd be more difficult to keep them charged because there's fewer sunlight hours, but animals are just happy to sit in the sun; Also animals that are willing to challenge the boundary more often, get more tones, and more impulses which reduces the battery life (Rancher #1).

When asked about their potential privacy concerns regarding the data being collected by these devices, none of the ranchers expressed any concerns about it. Only one interviewee mentioned concerns on a hypothetical scenario where those not in favor of meat production might obtain information on the location of their livestock.

3.3.4. Animal welfare: continued exposure to shocks

In the context of animal welfare, ranchers, and company representatives alike overarchingly felt that virtual fencing offered a net positive for animal welfare. Only one rancher wondered whether there could be adverse effects in animals resulting from continuous exposure to these shocks. Theye noted,

I have some concern about like just continually exposing the animals to like that emf radiation. I'm not gonna lose too much sleep over that (….) If you're, you know, really trying to produce the very best quality product you can, that could be a concern probably worthy of more study. (Rancher #5)

3.3.5. Uncertain relationships with fencing laws

Due to the novelty of virtual fencing technology in the US market, there is still uncertainty about how it will interact with existing fencing laws. This aspect was mentioned by a company representative, which noted that the relationship between virtual fencing and fencing laws is "uncharted territory". This representative exemplified the challenges with these laws, using the Iowa case,

Honestly, it's uncharted territory. It's a gray area. We have terms and conditions. We have a global lawyer. We address these things in our terms and conditions…At this point I feel like I could say, "no"—virtual fencing is not accounted for in legal fence law language, no. Is that an effort we should even be trying to go towards? Not sure we should get involved in those politics. I will say that [company name] has just made sure that our terms and conditions will hold up in court when and if that would arise. But yeah, that's a whole, that is a rabbit hole right there (Company # 1).

4. Discussion

This qualitative study explored virtual fencing for livestock—a technology just emerging on the US marketplace—through interviews with company representatives and ranchers in pilot programs. Our findings revealed that this technology has strong prospects coupled with considerable enthusiasm among ranchers who have had the opportunity to implement virtual fencing technology on their farms. Though nascent in the US marketplace, this exploratory research suggests that development of virtual fencing technologies harbors various possibilities to advance natural resources management on working lands by making it easier to effectively employ adaptive rotational grazing of livestock. Importantly, this research focused on ranchers and companies piloting products in Midwest states. Findings should therefore be interpreted within this specific context.

Findings are consistent with the topics covered in the literature exploring farmer perceptions on virtual fencing [37,38,40]. In their perceived benefits, ranchers noted the potential of rotational grazing, savings in time, money, and access to tracking information that can improve animal welfare.

Using targeted livestock grazing to manage vegetation has been shown to have environmental and nutritional benefits to the animals. But ensuring that there are adequate enclosures to facilitate their movements is challenging in terms of the labor and time that establishing and maintaining fencing—either electric of permanent—currently entails [45]. Participants in our study described how virtual fencing substantially alleviated these central challenges. Instead of spending hours moving electric fence to rotate livestock, ranchers draw a new paddock on their phone or tablet and observe the GPS signals from the livestock collars as they move. Participants further underscored that virtual fencing allows them to graze in areas previously inaccessible; they can draw a fencing line on terrain that would be challenging or impossible for people to reach. Participants noted how virtual fencing offered the flexibility to adapt to various landforms, allowing for paddocks designed in different shapes and sizes. This may improve ranchers' ability to use targeted grazing to reap different cited benefits, from managing undesired plant species such as dense underbrush and invasive species [10] to creating firebreaks that reduce fuel loads in overgrown ecosystems [9,46,47]. In this study, several participants were employing natural resource management approaches as a business through custom grazing.

All interviewed producers, operating at various scales and with different animals—goats, cows, and sheep—recognized benefits in utilizing virtual fencing. However, they also identified aspects of concern. Already, the financial costs of fencing is a key barrier to adoption of rotational grazing [45]. Participants did feel that virtual fencing offered savings in the costs and labor of establishing and maintaining fences, but as virtual fencing companies operating in the US are still in pilot phases, it is still uncertain how much these various products will ultimately cost to producers. Therefore, questions remain about how affordable virtual fencing will be for US ranchers. How will current pricing impact the diverse business models of ranchers? How might different products, each with their unique pricing structures, be accessible to varying ranchers? What constitutes the break-even point for virtual fencing across different operational and business models? Pertinent to these considerations on the associated costs with implementing a virtual

fencing system are the outstanding questions of costs to maintain and stay up to date with a still-evolving technology. In the context of an evolving technology, will the technologies require consistent product updates? What implications might such technological advancements hold for ranchers who are making the initial investment in purchasing collars now? Further research assessing the economics of virtual fencing products is important to explore these questions. These findings offer some nuance to the current literature, particularly related to price and profitability aspects, where the return on investment is a sensitive aspect [38].

Findings on collar functionalities and animal welfare also provide insight on the content of these challenges. In particular, a central issue relates to connectivity investment and the exact numbers of collars that are required. On connectivity, constructing base station model appears advantageous for large landscapes and circumvents issues related to areas with poor cellular network access. However, multiple base stations may be needed, which may represent a substantial investment. It remains to be seen what will be required in terms of maintenance of these base stations over time and the associated costs, not to mention who will have the technical expertise to maintain this infrastructure. On the number of collars, companies advise that each adult animal should wear a collar. This requirement could prove prohibitive for ranchers with large herds. Further research—and likely farmer experimentation—should explore whether there are strategies, based on scientific understanding of grazing behavior, that could reduce the need to purchase a collar for each animal.

Animal health and welfare is also a key consideration surrounding virtual fencing technologies. More broadly, past research has explored how information collected through sensors—as is the case for these collars—can help producers decrease losses from illness or other losses by providing real-time information on what is happening in the field [48]. A few short-term, small studies have conducted experimental trials to examine how the audio cues and electric pulses affect animal behavior in virtual fencing systems; these generally conclude that there is limited acute animal welfare implications [33,35,49]. Participants in our study felt that using virtual fencing systems enhanced ranchers' ability to manage animal welfare in their herds, describing how they could follow the GPS collar location to observe grazing patterns and changes in behavior. This also offered the benefit of being able to find an animal who is not with the herd or to find that a collar has fallen off and needs to be replaced. Despite the perceived benefits to animal welfare described in our study and the generally neutral animal welfare implications found in other research [35,36], noted public perceptions of negative animal welfare implications may arise as an issue to contend with if virtual fencing becomes more widely used in the U.S [38].

One of the key themes emerging from our results, which contributes to the research agenda on virtual fencing, is the uncertain relationship between virtual fencing technology and existing fencing laws [50], alongside the slow market rollout. These two aspects are intrinsically linked to both the current use of virtual fencing and its potential for broader adoption.

Currently, four companies offer virtual fencing services within the United States. While there is growing enthusiasm around this technology, uncertainties remain regarding the production capacity of these companies to manufacture collars and necessary equipment at scale. The slow rollout created additional uncertainty about how many collars could realistically be sold and utilized in the short-term, beyond pilot project efforts.

Our study suggests that the regulatory landscape for virtual fencing under various state-level fencing laws in the U.S. remains unclear, posing significant challenges for its widespread adoption. Ongard [50] highlights potential legal concerns, such as livestock trespassing due to GPS drift or ambiguity regarding property boundaries, which could lead to disputes with neighboring landowners. Additionally, there is the risk that animals might bolt through the virtual fence into dangerous areas, such as roads or cliffs. While some farmers may be interested in using this technology without physical fencing, if virtual fencing is not recognized as legal fencing in state regulations, they could face legal pressure from neighbors to maintain traditional physical barriers, in addition to the costs of VF. Moreover, it remains unclear whether programs like cost-share programs, such as USDA's Environmental Quality Incentives Program (EQIP) or the Conservation Stewardship Program (CSP), which offer Prescribed Grazing cost-shares [51,52], will permit the use of virtual fencing. Exploration on these aspects is crucial when strategizing the deployment and adoption of this technology.

The literature on digitalization raises social, ethical, and environmental concerns, focusing on issues like data ownership, accessibility, control, and power dynamics. However, the ranchers we interviewed did not express concerns about these topics. Instead, they emphasized that access to behavioral data improves animal care through consistent monitoring. As virtual fencing expands, future studies could explore these broader concerns, which may become more relevant as farmers gain experience with the technology.

Like other digital technologies in agriculture, there are outstanding questions of how data is collected and used—by ranchers and/or by the technology companies. Participants in our study saw positive potential to use the data collected through the GPS collars to both monitor animal behavior and remain informed about their welfare. In the medium-term, we see a potential to use these traceability functions to open opportunities for ranchers to enter carbon market programs, as these data could serve as evidence of the environmental benefits delivered through regenerative grazing. Future studies might explore how this relationship could be established. That said, it is yet unclear how virtual fencing companies will collect, access, and use ranchers' livestock data in the long-term. These companies should develop transparent data privacy policies to avoid future feelings of privacy violations.

5. Conclusion

Fencing has long been a critical agricultural technology in livestock ranching systems, but traditional fencing—and even more modern electric fencing—can be labor heavy and costly. In this paper, we consider how a new agricultural technology—virtual fencing—may impact how ranchers in the Midwest graze their livestock, with particular attention to opportunities to adopt adaptive rotational grazing practices. We presented results from qualitative interviews with representatives from companies emerging on the US market with virtual fencing products for livestock in addition to ranchers piloting the products in Midwest states. Still emerging on the marketplace, we identify benefits and current limitations that companies and ranchers perceive. These related to topics of environmental benefits, economic benefits (and challenges), current product efficacy in pilots, animal welfare considerations, and policy considerations, such as fencing laws and integration with conservation cost-share programs. As the market grows and products become more widely available, this information can inform how we engage with this technology—as ranchers, as farm agencies, as private industry, as researchers—and key questions to continue to explore.

Ethical statement

This study was approved and followed all guidelines by the University of Missouri's Institutional Review Board as an study (IRB# 2096541). We have followed all IRB guidelines to protect the privacy and confidentiality of our participants including reading approved consent script and obtaining consent in addition to cleaning and anonymizing all data prior to analysis and writing this manuscript.

CRediT authorship contribution statement

Jenny Melo-Velasco: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Kelly**

R. Wilson: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jocelyn Heimsoth:** Investigation, Data curation. **Robert L. Myers:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors do not have competing interests to declare.

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Data availability

The data that has been used is confidential.

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