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Comparison of virtually fencing and electrically fencing sheep for pasture management

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ABSTRACT

Context. Virtual fencing technology has potential for application in intensive grazing management. However, it is unknown whether the presence of the virtual fence will affect the grazing behaviour of sheep under intensive grazing situations. **Aims.** This study compared pasture consumption by sheep when pasture access is restricted using either a virtual fence ($n = 12$) or a conventional electric fence ($n = 12$), tested over three cohorts. **Methods.** The sheep were given access to a small section of pasture (8 × 8 m) for approximately 4 h, over a total of 4 days of grazing, being moved onto a fresh plot each day. Within the grazing plot, average pasture dry matter, normalised difference vegetation index (NDVI), and rising plate meter (RPM) height, were measured before and after grazing. NDVI and RPM height were also measured along the fence line before and after grazing. **Key results.** For within plot measures, there was no effect of treatment on biomass ($P = 0.42$), pasture height ($P = 0.69$) or NDVI ($P = 0.72$). The same was observed for measures taken at the fence line. The results of this study indicated that using a virtual fence to restrict access to pasture to create targeted grazing is as effective as using an electric fence. **Conclusions.** The similarity in pasture consumption between the groups indicated that the virtual fence does not affect normal grazing behaviour of sheep, nor discourage them from grazing up to the fence line. Further work should be conducted in larger flocks and using automated systems. **Implications.** Virtual fencing has the potential to be used to restrict sheep access to pasture to create targeted grazing that is as effective as is using an electric fence.

Keywords: electric fencing, grazing management, intensive rotational grazing, livestock management, precision agriculture, pasture utilisation, sheep, virtual fencing.

Introduction

Electric fencing is implemented in sheep production to intensify grazing management systems, such as subpaddock grazing, cell-grazing and techno-grazing (an intensive grazing system that uses paddock subdivision; Morris 2009, 2017). The ability to create subpaddocks by using temporary fencing is particularly of use in mixed farming systems, although electric fencing is often not used because of cost and labour requirements (Bell *et al.* 2014; Llewellyn *et al.* 2017). Virtual fencing has the potential to be implemented for grazing management and targeted grazing. It is a system that applies audio cues to warn animals that they are approaching a predefined boundary; if they do not respond to the 2.5 s audio warning (by continuing to walk forward), they receive an electrical pulse. Cattle and sheep readily learn the system to be successfully contained within a prescribed area (Campbell *et al.* 2017, 2018; Marini *et al.* 2018*a*, 2018*b*) and the welfare impacts following successful learning are minimal (Lee *et al.* 2018; Lee and Campbell 2021). The virtual fencing system has been effectively used with cattle grazing in rangelands (Campbell *et al.* 2020). However, work conducted in dairy cattle, which are often managed on intensive grazing systems, have found mixed results using virtual fencing systems to manage the herd (Lomax *et al.* 2019; McSweeney *et al.* 2020; Langworthy *et al.* 2021).

If virtual fencing is to be used for grazing systems such as strip-grazing, it is important that sheep associate the virtual fence only with the audio cue, and not the location, so they walk through previous boundaries if the fence is moved. Virtual fencing has previously been used to restrict a small group from a subsection of a paddock before the boundary was removed, allowing the sheep full access to the paddock again (Marini *et al.* 2018*a*). After the virtual fence was removed, the sheep readily crossed the previous boundary line, accessing the rest of the pasture (Marini *et al.* 2018*a*).

As sheep learn the virtual fence, they readily respond to the audio cue avoiding the location of the fence line (Marini *et al.* 2018*a*, 2018*b*). This, combined with the aversive nature of the electrical pulse, raises the concern that the sheep will avoid grazing along the fence line, hence reducing utilisation of pasture. Cattle have also been shown to use the paddock differently when exposed to a moving virtual fence, moving into previously inaccessible areas when the virtual fence has been moved from the location (Campbell *et al.* 2017, 2019*a*, 2020).

Currently there are no reliable automated virtual fencing systems for sheep (Jouven *et al.* 2012; Brunberg *et al.* 2016, 2017) and research work is often conducted using a manually implemented system (Marini *et al.* 2018*a*, 2018*b*). This current study proposed to test the implementation of a manually applied virtual fencing system for pasture management by using a small group of sheep, compared with sheep confined with an electrical fence, in an intensive rotational grazing management system where the flock is shifted onto a new subsection of the paddock every few days (Colvin *et al.* 2008; Savian *et al.* 2018). We aimed to compare pasture utilisation and grazing pressure at the fence line between virtually fenced and electrically fenced sheep, by using an intensive grazing method. It was hypothesised that with a high pasture utilisation rate, there would be no difference in pasture utilisation between the sheep contained with an electrical fence and those contained with a virtual fence. The second hypothesis was that the virtual-fence group would graze along the front fence line with less intensity than would the electrical fence group, because of the uncertainty of its location without the visual cue of the electrical fence.

Materials and methods

Experimental design

The protocol and conduct of the experiment were approved by the CSIRO Chiswick Animal Ethics Committee under the *NSW Animal Research Act* 1985 (approval ARA 18/18). The study was conducted in August–November of 2018 at CSIRO FD McMaster Laboratory's Big Ridge (30°20′35″S, 151°37′07″E, Armidale, NSW, Australia), by using 36 3-year-old Merino ewes (average weight ± s.e.m., 38.2 ± 0.55 kg). All sheep were weighed and branded with sheep-branding fluid for identification (Colourflow, Heiniger, Australia) before the study began. An experimental plot was planted to a forage barley crop (Dictator II, Barenbrug, Melbourne, Vic., Australia) on 5 August 2018 at 70 kg/ha, and first grazed on 30 October 2018. The paddock was divided into six equal strips (east to west) with permanent four-strand wire fencing, and a shade cloth covered fencing in between the third and fourth strip, dividing the strips into two blocks of three strips each.

The experimental design consisted of two grazing management treatments (electrical fence and virtual fence), and three replicated experimental periods of 4-day duration each, conducted over a period of 3 weeks. Each week, two new strips of the barley crop (one from each block of the paddock, and each subdivided into four 8 × 8 m subplots; Fig. 1), and a new cohort of sheep were used. On each day of each experimental period, a flock of six sheep from the electrical-fence treatment and another from the virtual-fence treatment were simultaneously grazed on a different subplot of the barley crop for 4 h each day, with *ad libitum* access to water. A fresh subplot was grazed each day in each strip of the barley crop. There was a 2 m strip of ungrazed buffer between subplots. The treatment groups were rotated between the two crop strips, alternating blocks of the paddock every day for the 4-day experimental period (Fig. 1). The two-crop strips used in each experimental period were separated by 16 m, and a shade cloth-covered fence, to prevent visual contact between the treatment groups (Fig. 1).

Animals and care

Access to the crop occurred between the hours 08:30 and 14:00 during the experimental periods. The sheep were held in pens when not grazing the crop and supplemented

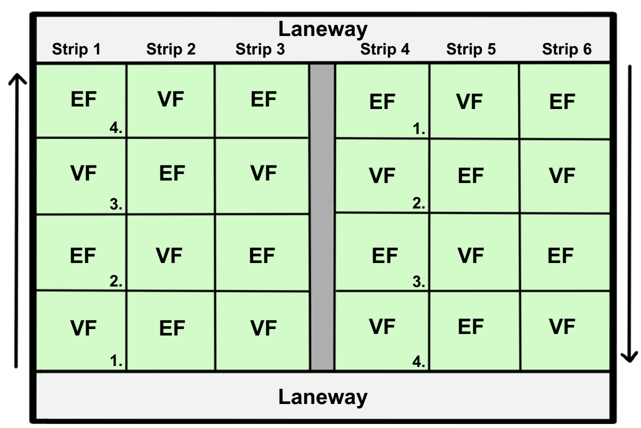

Fig. 1. Schematic of the study site. The virtual-fFence (VF) and electric-fence (EF) groups were swapped between the laneways each day. Fencing is shown as black lines. Shade cloth was located on the fencing to block the groups' views (grey). All plots were 8 × 8 m with a 2 m buffer between each new plot. Arrows indicate direction of grazing rotation within a strip between days (north for Strips 1–3, south for Strips 4–6).

with lucerne hay (500 g/sheep.day). When not part of the experimental grazing periods, sheep were returned to a farm paddock. The sheep allocated to the virtual-fence group had previously been used in a virtual-fencing study and had prior experience with the virtual fence and the equipment used to implement the fence. The sheep in the electric-fence group had no known prior exposure to electric fencing.

Virtual-fence training

The week before the grazing experiment, all sheep in the virtual-fence group underwent a 2-day virtual-fence training to ensure that all the sheep were able to pair the audio cue with the electrical stimulus. To conduct the training, the sheep were walked down a small race that contained a feed reward at the end. They were trained this way first in pairs and then individually. As they approached the feed reward, an audio cue was given for 2 s; if they continued to walk forward, they received an immediate shock (<1 s). Training occurred twice a day over 2 days, each test was 3 min.

Implementation of grazing management

Sheep in both treatment groups were fitted with a Garmin collar weighing 297 g (Garmin TT15, Olathe, KS, USA) during the grazing period. Wool around their necks had to be clipped before the collars were attached. These collars were used to track the sheep location throughout the experiment by GPS, with only the virtual-fence group having the collars configured for the fence. During the experimental grazing, the flocks of sheep in the virtual-fence group were kept in their subplots using the virtual fence (via the Garmin collars) in the front of the subplot, permanent fencing on the sides and a panel fence behind. If a sheep started walking towards the virtual-fence line, they were given an audio cue for 2 s. If they continued to walk forward or did not alter their behaviour (i.e. turn around) in the warning zone after their 2 s audio cue, an immediate shock (<1 s) was given. If the animal ran out of their grazing section (past the virtual fence), all cues were ceased until the animal had stopped running. Once the animal was calm, the audio cue and a stimulus were implemented if it proceeded further away from their grazing section, until they turned around and returned to the subplot. The flocks of sheep in the electric-fence group were kept in their subplots during the experimental grazings, using portable four-strand electric fencing (Smart fence 2, Gallagher, Vic., Australia) on the front of the subplot, with permanent fencing on the sides and a panel fence behind.

Pasture measurements

Non-destructive pasture measurements were taken using the GeoSCOUT, (GeoSCOUT, GLS-400, Holland Scientific, USA) in each subplot before and after each grazing period. The GeoSCOUT collected pasture height, biomass and normalised difference vegetation index (NDVI), which quantifies vegetation by measuring the difference between near-infrared and red light (Hanna *et al.* 1999; Trotter *et al.* 2010). An additional 20 non-destructive measures of NDVI (Trimble GreenSeeker, Trimble, USA) and rising plate meter (RPM) were taken along the electric and virtual fence line (at the front of each subplot, location where audio was applied) before and after grazing.

A single pre-grazing calibration equation for each crop-strip was calculated at the start of each experimental period from 12 30 × 30 cm quadrats (12 cuts per strip, covering the range of pasture biomass on offer). A post-grazing calibration equation was calculated daily for each subplot from four quadrats per subplot, covering the range of pasture biomass on offer, after non-destructive post-grazing measurements were collected. For each quadrat in the pre- and post-grazing calibrations, NDVI and RPM height were measured before the barley forage in the quadrat was cut, bagged and dried at 60°C for 48 h and then weighed for dry biomass.

Calibration equations were fitted to predict dry biomass from (1) RPM height, (2) NDVI and (3) an index of RPM height × NDVI. The resulting calibrations were compared for coefficient of determination (r^2). The index of NDVI × height was the most consistent and appropriate predictor of pre-grazing dry biomass estimation (kg DM/ha) throughout the experiment. Separate calibration equations were then applied for each subplot on each day for post-grazing dry biomass estimation. A suitable calibration could not be determined from the destructive measures for Crop-strip 3, so the calibration from Crop-strip 6 was used for both strips in Experimental period 3. The calibrated estimates of dry biomass were analysed to determine the total utilisation (difference between pre- and post-grazing dry biomass).

Statistical analyses

All data were analysed using the statistical software program R (R Development Core Team ver. 4.0.2), and the nlme package (Pinheiro *et al.* 2018). Data were tested for normality through visual inspection of residual plots and the Shapiro–Wilks test. A P-value of <0.05 was considered statistically significant and $0.1 > P > 0.05$ was considered a statistical tendency.

To test the hypothesis that with a high pasture utilisation rate, sheep will graze the pasture uniformly in both groups, but the virtual-fence group will graze with less intensity close to the subplot boundaries, within-subplot destructive and non-destructive measurements, and front fence-line measurements were analysed using a linear mixed-effects model. Starting with the maximal model that included all predictors and interactions, the most appropriate model that fitted the data was selected on the basis of information criterion (Akaike information criterion (AIC) and Bayesian information criterion (BIC); Gygax 2014; Srivastav *et al.* 2014). Crop-strip was fitted as a random effect.

For the virtual-fence treatment, animal interactions with the fence were recorded, and the proportion of electrical stimuli to audio cues applied was calculated but not analysed. The most appropriate model on the basis of information criterion included cohort, treatment and day and the interaction of treatment × day as fixed effects.

Results

For within-subplot measures, there was no effect of treatment on mean calibrated destructive dry biomass ($F_{(1,11)} = 0.7$, $P = 0.42$), mean GeoSCOUT biomass ($F_{(1,11)} = 0.69$, $P = 0.42$), RPM height ($F_{(1,11)} = 0.17$, $P = 0.69$) and NDVI ($F_{(1,11)} = 0.14$, $P = 0.72$; Table 1). No effect of day or cohort was found for any of the measures ($P > 0.05$). There was a treatment by day interaction ($F_{(3,11)} = 3.49$, $P = 0.05$) for RPM height, with the electric-fence group having a lower change in RPM height (pre- to post-grazing) than did the virtual-fence group on Day 1 (mean = 0.85 cm vs 6.53 cm respectively, $t_{(11)} = 2.89$, $P = 0.01$). A difference in RPM height was also observed between the electric fence Days 1 and 4 (mean = 0.85 cm vs 5.26 cm, $t_{(11)} = 2.33$, $P = 0.04$). For subplot edge biomass estimation, there was no effect of treatment ($F_{(1,7)} = 0.79$, $P = 0.40$), day ($F_{(1,7)} = 0.79$, $P = 0.53$) or cohort ($F_{(1,3)} = 0.17$, $P = 0.85$; Table 1). Throughout the study, each strip had ample pasture available before and after grazing (Table 2).

The ratio of electrical stimuli to audio cues applied to the virtual fence cohorts was 0.11 for Cohort 1, 0.10 for Cohort 2 and 0.13 for Cohort 3. There was an instance in the first virtual fence cohort of one ewe breaking the fence line and moving beyond the allocated grazing plot. The other five ewes in this group continued to be successfully contained, with the uncontained ewe eventually turning back by the virtual-fencing cues and returning to the allocated grazing plot within 10 min.

Discussion

In this study, we investigated pasture utilisation in an intensive grazing situation when using either a virtual fence or an electric fence to restrict animal movement. When sheep had access to a barley crop pasture during a 4-h period over 4 days, there was no difference between the groups in the amount of pasture consumed. The intensity of grazing close to the virtual- or electric-fence line was also examined, with no differences in grazing pressure found. The findings of this study are similar to observations in cattle, when comparing behaviour and welfare of cattle either contained using a virtual fence or an electric fence, with no considerable effects being reported (Campbell *et al.* 2019*b*). Our findings are positive for the application of virtual fencing as a grazing management tool for sheep in intensive grazing systems.

The results of this study are similar to those reported in dairy cows that were kept within their allocated

Table 1. Mean change in RPM height, NDVI and estimated biomass within subplot and at fence line, pre- to post-grazing.

Parameter	Calibrated dry-biomass estimation (kg DM/ha)	RPM height (cm)	NDVI	GeoSCOUT biomass estimation (kg/ha)
Within plot				
EF	672.07 ± 346.55	3.97 ± 0.91	0.14 ± 0.01	326.35 ± 42.87
VF	652.94 ± 438.35	4.43 ± 1.11	0.13 ± 0.01	278.83 ± 55.31
P-value	0.42	0.69	0.72	0.42
Fence line				Biomass estimation (kg/ha)
EF	NA	4.37 ± 3.09	0.08 ± 0.05	205.46 ± 120.06
VF	NA	3.64 ± 1.35	0.04 ± 0.03	197.54 ± 144.99
P-value	NA	0.88	0.65	0.40

Data are presented as means ± s.e.m. for the electric-fence group (EF; n = 12 subplots) and virtual-fence group (VF; n = 12 subplots). NA, not available.

Table 2. Mean GeoSCOUT height, normalised difference vegetation index (NDVI) and estimated biomass within subplot, pre- and post-grazing.

Parameter	GeoSCOUT height (cm)		GeoSCOUT NDVI		GeoSCOUT biomass estimation (kg/ha)	
	Pre	Post	Pre	Post	Pre	Post
EF	11.58 ± 0.8	7.58 ± 0.7	0.54 ± 0.02	0.40 ± 0.02	2677 ± 168	1793 ± 172
VF	11.14 ± 0.7	8.62 ± 0.7	0.54 ± 0.02	0.41 ± 0.02	2630 ± 175	2065 ± 172

Data are presented as means ± s.e.m. for the electric-fence group (EF; n = 12 subplots) and virtual-fence group (VF; n = 12 subplots).

grazing plot using virtual fencing (Langworthy *et al.* 2021). Langworthy *et al.* (2021) compared the use of an electric fence versus eShepherd virtual fencing at containing dairy cows within their allocated pasture as well as determining pasture utilisation. They found that the virtual fence was effective at containing the cows within their allocated pasture, even as the feed available decreased. In our study, sheep still had adequate pasture available at the end of each grazing period and may not have been as motivated to challenge the virtual fence. It is unknown whether sheep would have been effectively contained if they were motivated to graze outside the virtual fence when pasture availability was low. A previous study demonstrated that sheep will increase interactions with the virtual fence as pasture availability in the inclusion zone decreases (Marini *et al.* 2020). The dairy cows in the Langworthy *et al.* (2021) study also did not avoid grazing close to the virtual fence line as was seen in our sheep study. However, Langworthy *et al.* (2021) found that pasture utilisation in the virtual-fence group was reduced compared with that in the electric-fence group.

The proportion of electrical stimuli to audio cues in this current study was lower than previously reported in sheep, with a lower ratio indicating less electrical stimuli to audio cues. Sheep received between 0.10 and 0.13 electrical stimuli per audio cue, whereas previous studies with groups of sheep exposed to the virtual fence have reported proportions between 0.19 and 0.28 (Marini *et al.* 2018*a*, 2020). Unlike previous studies, sheep in this current study had already been exposed to the virtual fence in a larger paddock setting as well as during individual training before partaking in the experiment. This may account for their better response to the audio cue, even though they were confined within a much smaller space. The pre-training was conducted to allow the sheep to be effectively contained by the virtual fence without requiring them to learn within the confined space. Previous studies with sheep that investigated training naive animals to the virtual fence used much larger paddock sizes. In these studies, behaviours such as running forward or turning and running backwards is commonly seen when sheep are learning the virtual fence (Marini *et al.* 2018*a*, 2018*b*, 2019). It would have been unreasonable to train naive animals in an 8 × 8 m area as they would not have been able to effectively display these behaviours while staying within the boundary and there could have been a risk to their welfare.

The implementation of virtual fencing in intensive grazing systems can address the high costs associated with the labour of erecting and moving temporary barriers such as electric fencing. Intensive grazing management of sheep is often implemented as part of mixed cropping systems (Francia *et al.* 2006; Morris 2017), as it allows producers to diversify income (Llewellyn *et al.* 2017), improve productivity (Bell *et al.* 2014), control weeds (Nie *et al.* 2016) and improve pasture utilisation. When rotation is included in intensive grazing systems, there are also additional benefits for the livestock, such as improvement in gastrointestinal parasite control (Colvin *et al.* 2008) and mitigation of methane emissions (Savian *et al.* 2018).

This current study was conducted in much more restricted paddock sizes and much smaller flock sizes than would traditionally be used on farm and with grazing management practices such as strip grazing. The small paddocks were implemented so as to effectively measure pasture impacts because of the smaller flock size. However, this method of grazing would not be recommended in practice because of the difficulties of containing sheep. Also our study did not account for the potential virtual fence line wobble that may be seen in GPS-driven fence lines, which could potentially affect the pasture results.

Conclusions

The results from the present study indicated that using a virtual fence to restrict sheep access to pasture to create targeted grazing is as effective as is using an electric fence. The similarity in pasture consumption between the groups indicated that the virtual fence neither affects normal sheep grazing behaviour nor discourages sheep from full utilisation of the available grazing area. Further studies should be conducted using larger flocks and with automated systems that would allow for longer access time to pasture as well as including virtual-fence movement.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

Conflicts of interest. The authors declare no conflicts of interest.

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