Automating dairy farm grazing records using GPS technology

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Abstract

Long-term grazing records can be used to assess paddock productivity (e.g., grazings per year), yet inconsistent record-keeping among New Zealand farmers hampers accurate analysis. Recently, GPS ear tags have emerged as an automated solution for identifying and recording paddocks grazed, providing data that could be used to underpin on-farm decisions and aid sector scale tracking of pasture productivity. Two GPS-enabled ear tags (GSatSolar and Ceres Trace) powered by solar energy and reporting direct-to-satellite were evaluated on two Waikato dairy farms for recording grazing events. Five cows were fitted with GSatSolar ear tags on each farm, and a further four were fitted with Ceres Trace ear tags on the second farm. Comparing the GPS location data with manual grazing records revealed varying levels of accuracy in identifying the grazed paddock. The grazing records inferred using the GSatSolar ear tags correctly matched the manual grazing records on 58% of occasions on the first farm and 85% on the second farm, with the difference being attributed to the number of working devices between farms. By comparison, the Ceres Trace ear tags identified the grazed paddock on 91% of occasions. These findings suggest that it is feasible to automate the recording of on-farm grazing events using GPS-enabled devices. However, more devices should be deployed, and/or the location reporting frequency must be increased to identify the grazed paddock accurately. The considerations when choosing devices for these purposes are also discussed, including reporting frequency and tag attachment methods.

Keywords: Animal location, pasture management, livestock monitoring, paddock productivity, precision agriculture

Introduction

Well-managed pasture is critical for milksolids production and farm profitability in pasture-based dairy systems like New Zealand. Pasture growth in temperate regions of New Zealand occurs year-round following a seasonal pattern and represents the primary feed source (Holmes et al. 2002; Neal and Roche 2019). Maximising pasture use, a low-cost, high-quality feed source, has several advantages, including reducing farmers' reliance on imported feeds and aiding in cost reduction (Rotz et al. 2020; Palma-Molina et al. 2023). On an international level, a predominantly pasture-based system aids the New Zealand dairy industry's competitiveness against more intensive dairy systems commonly used overseas, such as the United States (Neal 2021).

Despite the acknowledged importance of pasture in New Zealand dairy systems, regular pasture mass assessments to provide the information needed to optimise pasture management are often overlooked on New Zealand dairy farms, particularly during busy periods like calving (Anderson and McNaughton 2018). Dela Rue and Eastwood (2023) reported in a survey of 500 dairy farmers that 10% did not monitor pasture over the spring period. Among those who did, 54% relied on subjective visual estimates, while 22% used a rising plate meter. Dela Rue and Eastwood (2023) estimated that 40% of farmers in their survey measured pasture weekly, half using technology and the other half assessing visually. However, this data tends to be used only for short-term decisions, such as daily paddock allocation, with no systematic collation or retention (Stevens and Knowles 2011). Similarly, records of paddocks grazed are often lacking. Dela Rue and Eastwood (2023) reported that 45% of farmers use some form of software to record and analyse pasture data, while 18% of farmers use digital platforms such as a personal computer or phone app to record which paddocks were grazed.

Grazing records, including pasture measurements, should play a pivotal role in informing decisions related to pasture management, including regrassing (McSweeney et al. 2022). Systematically recording grazing events helps farmers identify underperforming paddocks due to issues like pests, poor drainage, or low-yielding species (Kerr et al. 2015). Targeted interventions to remedy the underlying cause of poor performance can improve pasture growth and reduce supplementary feed needs. Grazing records can also be integrated with supplement data (i.e., supplements purchased and supplements conserved) to estimate pasture growth or used as an input into pasture growth forecasting.

One practical solution to streamline the capture of on-farm grazing events is utilising Global Positioning

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System (GPS) devices, as suggested by Haultain (2014). These devices offer a convenient and efficient means of recording grazing activities without imposing undue burdens on farmers' time and resources. By leveraging technology to gather and analyse grazing data, farmers can make more informed decisions regarding pasture management, enhancing the sustainability and profitability of their operations. Similarly, GPS devices could assist farmers in providing proof of grazing to milk processors, regional councils, or other relevant stakeholders, delivering value for compliance or provenance.

Advancements in GPS technology have led to increased accuracy, precision, and reduced costs, sparking a resurgence of interest in its application within the agricultural sector. Recent studies have highlighted the potential of GPS devices for recording on-farm grazing events or estimating pasture mass in combination with other data, such as spectral data (Haultain 2014; Woodward et al. 2019; Hofmann 2022; Hofmann et al. 2023). However, devices used in these studies were either battery-powered or necessitated an on-farm base station, which incurred additional cost and maintenance time. They also had potential range issues on some farms, hindering widespread adoption.

An alternative approach is to use GPS ear tags powered by solar energy and equipped with direct-to-satellite communication capabilities. These ear tags utilise low earth orbit satellites for transmitting GPS data, offering a promising solution for automated paddock grazing record keeping. This paper presents findings from an on-farm study evaluating the feasibility of automating paddock grazing records by deploying GSatSolar (Global Satellite Engineering) or Ceres Trace (Ceres Tag Pty Ltd) ear tags on a subset of the dairy herd. We also use information from this study and prior research to guide researchers, developers, and farmers on how to use and improve these systems.

Materials and Methods

Experimental sites and set-up

Cow GPS and on-farm grazing records were gathered from two Waikato dairy farms in the 2023/24 milking season (152-day period). Farm A, near Te Kuiti, employed GSatSolar ear tags, while Farm B, situated at Horsham Downs (approximately 15 km from Hamilton), utilised both GSatSolar and Ceres Trace ear tags. This study was conducted with approval from the AgResearch Animal Ethics Office (Ref: 2023-0658).

Farm A

The farm was of rolling to steep topography with approximately 620 spring calving cows divided into two main herds (based on age) and milked once daily. It comprised approximately 46 paddocks averaging 4 hectares each. The farm utilised a grass-based system for the dairy herd, with palm kernel extract fed in the paddock when required, such as during periods of feed deficits (e.g., early spring and summer). Within the younger herd (2 + 3-year-old cows) of 225 cows, five cows (~2.2% of the milking herd) were randomly selected and fitted with a GSatSolar device as an ear tag between August 2023 and January 2024. Depending on paddock size, the cows were allocated a 12-hour or 24-hour pasture break.

Farm B

Farm B was characterised by its flat terrain and consisted of 40 paddocks, each averaging 1.8 hectares. The farm maintained a herd of approximately 240 cows, milked once daily as a single main mob during calving and early spring. After transitioning to a twice-daily milking schedule for 6 weeks during mid-spring, the farm then reverted to once-daily milking for the remainder of the milking season. The farm used a feed pad regularly during early lactation and the summer/autumn periods, feeding palm kernel extract and maize silage. Between August 2023 and January 2024, five cows from the existing milking herd (~2.1% of the milking herd) were fitted with GSatSolar devices either as an ear tag (two cows) or attached to a standard cow collar (three cows) (see Figure 1) and a further four cows (~1.7% of the milking herd) with a Ceres Trace ear tag.

Devices

GSatSolar

The GSatSolar (Fort Lauderdale, Florida, United States) ear tag (Figure 1a) is a reusable single-pin solar-powered ear tag measuring 31.8 mm × 57.1 mm × 17.8 mm (W × L × D) and weighing approximately 26 g. The devices are accurate to around 2.8 m (SE (standard error) 0.03 m) average error from the actual location based on static testing by the authors at DairyNZ's Scott Farm, Newstead, New Zealand, a flat dairy farm (data not presented). For this study, the devices used firmware 2.12.0 and were set to record six positions daily (every 4 hours) utilising the Globalstar Satellite Network. Essential information recorded by the devices included location (latitude and longitude), date and time of observation. GPS data can be viewed at no cost via the manufacturer's web portal.

Ceres Trace

The Ceres Trace (Brisbane, Queensland, Australia) ear tag (Figure 1b) is a twin-pin solar-powered ear tag designed for lifetime animal traceability and hence cannot be reused. It measures 51 mm × 62 mm × 8 mm (W × L × D), weighs 29 g and is accurate to around 3.2 m (SE 0.1 m) of the actual location based on static

Figure 1 GPS devices on dairy cows during the trial period. Photo (a) on the left shows a GSatSolar ear tag attached to a cow collar, while photo (b) on the right displays a Ceres Trace ear tag (white rectangle).

testing by the authors (data not presented) conducted concurrently with the GSatSolar devices above. The manufacturer sets this tag to transmit up to four GPS positions daily using the Globalstar Satellite Network, and it includes 3 years of satellite connectivity, which is suitable for the typical lifespan of tagged animals in beef finishing systems, which was the original focus of its design. This tag also provides information on ambient temperature, animal activity, and location data. Once data is transmitted, it can be accessed through various software providers, with Mapipedia (Brisbane, Queensland, Australia) being the chosen provider for this study. The cost for Mapipedia was NZ$33 per month, with an additional NZ$0.80 per tag.

Data analysis

For both farms, the devices remained attached to the same animals regardless of whether they stayed in the main milking herd or were drafted into a secondary herd for treatment or other purposes. Following the trial conclusion, the GPS data was downloaded in Microsoft Excel format from the manufacturer's web portal for the GSatSolar ear tags or from Mapipedia for the Ceres Trace ear tags. The daily grazing records on both farms were manually recorded on a farm whiteboard before being transcribed into a Microsoft Excel spreadsheet to enable data analysis. All analyses were performed using R Statistical Software (v4.2.1; R Core Team 2022), RStudio (v2023.06.2; Posit Team 2023), and the latest libraries (e.g., tidyverse, lubridate and sf) at the time of analysis.

Digital maps (shapefiles), which included various farm features such as paddocks, cowsheds, and farm laneways for each trial property, were provided by the farmer or other industry stakeholders. The GPS data points were matched with corresponding paddocks or other farm areas, such as the cowshed or feed pad, utilising the st_join function within the sf package in R (v1.05.15; Pebesma 2018; Pebesma and Bivand 2023), enabling the identification of specific paddocks grazed during the trial period. The creation of digital maps and subsequent analysis of GPS data was performed using the sf package in R.

All timestamps from the GPS devices were initially recorded in Coordinated Universal Time (UTC), and these were subsequently converted to New Zealand dates and times (NZST and NZDT to account for daylight savings where applicable) using the R lubridate package (v1.9.3; Grolemund and Wickham 2011). This was done to align the dates and times with the manual grazing records.

Each day was conceptually divided into grazing intervals to identify the paddock grazed during each period. For example, the AM grazing was from 06:00 to

15:00. In contrast, the PM grazing time was partitioned into two distinct intervals: 15:00 to 00:00 and 00:00 to 06:00. The 00:00 to 6:00 period for the GPS records was then associated with the previous day to ensure proper alignment of the GPS records with manually recorded grazing observations (e.g., this period related to the previous day's manual grazing records). The herd's most probable paddock(s) were determined by identifying the area with the highest density of GPS observations within each grazing period. If the area was the cowshed or feed pad, it was excluded, and the next highest recorded area was selected, as the focus was identifying the paddock(s) grazed.

Following data processing, the GPS-derived grazing records were compared with the manually documented grazing records to evaluate the accuracy of GPS-based identification of paddock grazed. This evaluation provided insights into the effectiveness and reliability of GPS technology in identifying the paddock(s) grazed.

Results

During studies at Farms A and B, mixed results were observed regarding the performance of the GSatSolar devices. On Farm A, the GSatSolar devices recorded 1200 observations over the experimental period compared with an expected 4560 observations (number of devices applied × daily fixes × number of days in the trial). Of these, 89.8% occurred within defined grazing areas, 6.2% in undefined regions (e.g., farm laneways), and 4% at the cowshed. However, four of five devices failed to record GPS data for the whole period but remained attached to the animal. These four devices accounted for 16% of the observations, with the remaining device recording 84%. The one device that reported GPS positions throughout the experiment reported an average of 6.5 daily positions, consistent with its programmed rate of six.

Challenges were also noted on Farm B: one device stopped functioning, another was lost from the ear, and a third was dislodged from its collar and not replaced. Consequently, at the trial conclusion, only two operational ear tags remained on Farm B. The two operational GSatSolar ear tags affixed to collars captured 1319 observations from an expected 4560 observations. Of these, 89.4% were within designated grazing areas, 5.4% occurred in undefined regions, 3.3% were at the cowshed, and 1.9% were at the feed pad. These ear tags reported around five positions per day, slightly below the programmed rate of six. Figure 2 summarises the daily positions of the best two GSatSolar devices for each farm during the experimental phase.

By contrast, the four Ceres Trace ear tags remained attached throughout the experiment, logging 1831 GPS observations from an expected 2432 observations. Of these, 91.3% were within paddocks, 3.9% in undefined areas, 2.6% at the cowshed, and 2.2% at the feed pad. On average, each tag recorded three positions per day, achieving near the manufacturer's limit of up to four positions per day per tag. Figure 3 shows the daily observations collected from the Ceres Trace ear tags during the experimental phase.

After identifying the area with the highest GPS observations within each grazing period (as shown in Figure 4), the comparison with manual records for the corresponding period revealed that GPS records matched the grazed area 58% of the time for Farm A and 85% for Farm B using the GSatSolar ear tags. For Farm B, 91% of the GPS grazing records were correctly matched with the manual records using the Ceres Trace ear tags.

Discussion

Paddock identification accuracy using GSatSolar ear tags was lower on Farm A compared to other farm studies using GPS devices for the same purpose, while the results were similar to published data on Farm B using either GSatSolar or Ceres Trace ear tags (Hofmann et al. 2022; Hofmann et al. 2023). Several factors may have contributed to differences between farms, including the difference in topography between farms potentially affecting device accuracy (e.g. flat vs. rolling), errors in recording daily grazing data or tagged cows being in the incorrect grazing mob on the farm. Compared to previously published research, there is also a difference in the number of ear tags deployed per herd, tag reporting frequency, and the number of ear tags that remained operational at each farm. For example, in this investigation, only about 2% of the herd wore GPS devices, contrasting with the 10% or higher in an earlier study by Hofmann et al. (2023). Furthermore, prior studies by Hofmann (2022) and Hofmann et al. (2023) utilised GPS devices with more frequent reporting, such as hourly or two-hourly updates, instead of the four-hourly or six-hourly intervals in this study. Lastly, throughout the 6-month trial on Farm A, only one GSatSolar ear tag remained functional out of the initial five deployed, whilst on Farm B, only two remained functional. Consequently, the daily availability of GPS fixes crucial for identifying grazing areas was reduced by 60% or more for this technology.

The feasibility of implementing this technology within New Zealand's dairy farming sector depends on several factors, including the reliability of GPS devices, which will affect the number of animals required to be fitted with devices, farm topography (satellite and cellular availability, device accuracy), and expected solar radiation for charging if using solar-powered

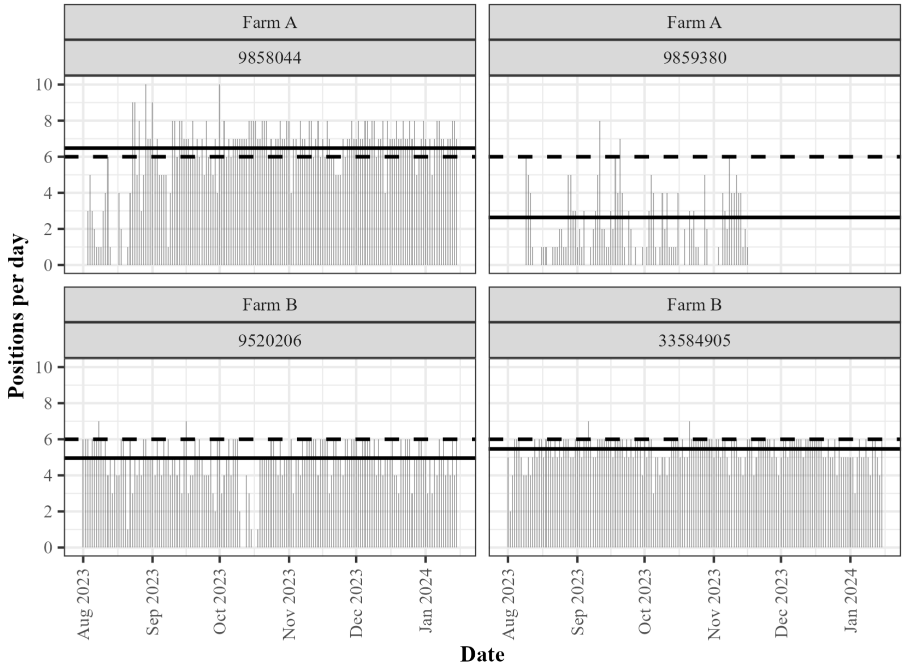

Figure 2 Daily positions recorded by four GSatSolar ear tags during the experiment. The solid line shows the mean positions per day, and the dashed line shows expected daily fixes.

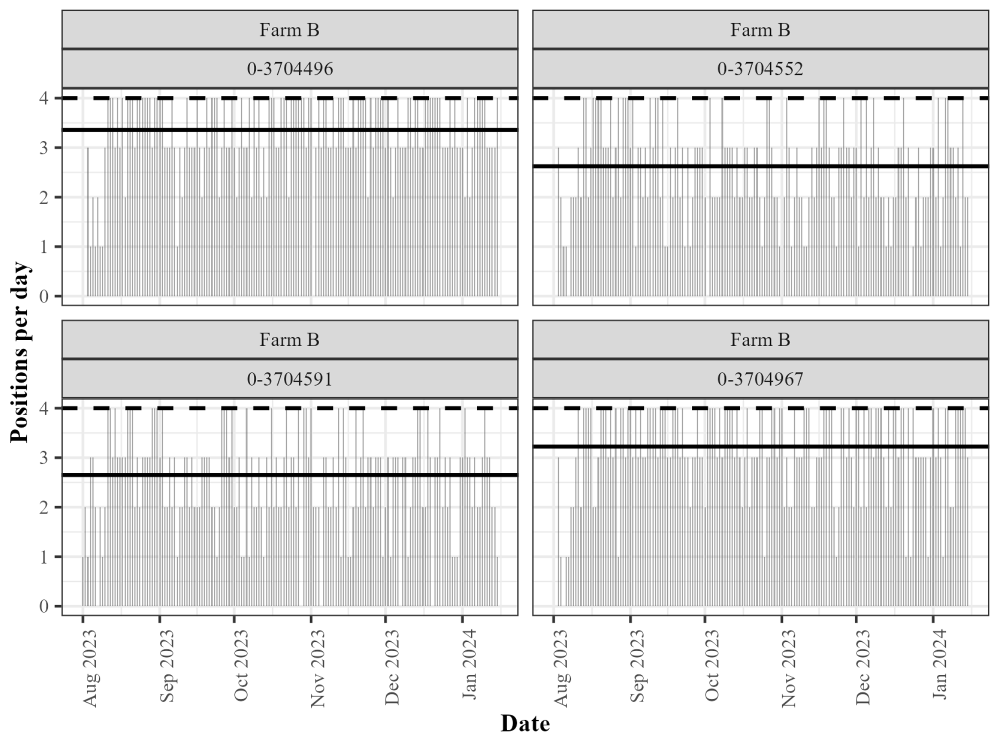

Figure 3 Daily positions recorded by four Ceres Trace ear tags during the experiment. The solid line shows the mean positions per day, and the dashed line shows expected daily fixes.

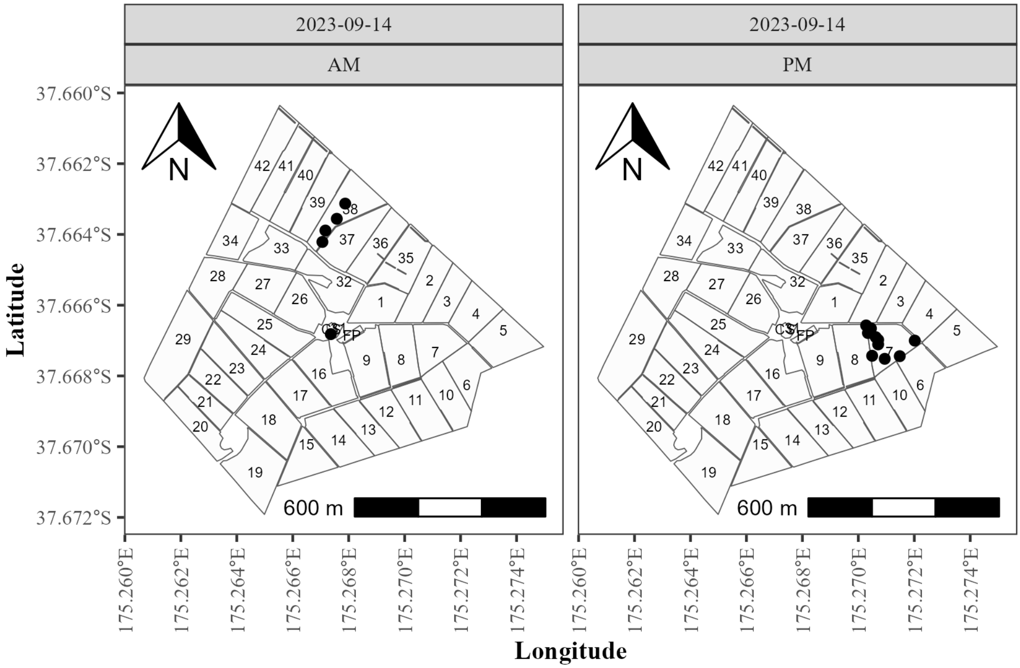

Figure 4 GPS points from four Ceres Trace ear tags at Farm B, with AM grazing from 06:00 to 15:00 and PM grazing from 15:00 to 06:00.

devices as opposed to battery-powered devices. Other considerations include the cost of individual devices and on-farm practicality, such as the number of devices needed, whether a specialised applicator is required to apply the devices, or other special equipment, such as a base station. The GPS ear tags used in this study, including the data package, ranged from NZ$275 to NZ$280, with additional costs for the applicator required to apply the Ceres Trace ear tags (NZ$800).

From a practical perspective, integrating GPS devices into on-farm practice appears to be operationally viable; nevertheless, several on-farm complications require careful consideration. Among particular concern is ensuring the consistent presence of the requisite number of monitored animals within each mob, particularly during transitional phases such as early or late lactation, when cows may migrate between groups for calving or dry-off. To minimise this challenge, one option may be to attach some GPS devices to collars rather than ear tags since collars can be easily moved between animals. This approach ensures that enough animals are equipped with GPS devices in each mob, facilitating the acquisition of reliable location data throughout the year to identify grazing areas accurately.

When selecting GPS devices for identifying grazed areas, the fix rate, the frequency at which a GPS position is recorded, stands out as a critical consideration. A higher fix rate, such as every 30 minutes compared to once every 4 hours, enhances the accuracy of grazing area identification (Turner et al. 2000; Swain et al. 2008). Additionally, a higher fix rate reduces the number of animals needing GPS devices, thus lowering costs. However, fix rate considerations cannot stand alone. For example, the fix rate can be influenced by numerous factors, including the topography, device orientation, scheduled fix interval and canopy closure, such as the presence of trees (Frair et al. 2010). A higher fix rate will also increase the battery demand of GPS devices, which may not be sustainable for small devices that rely on solar power, such as the devices in this study. Hence, a balance among a range of factors, including fix rate, required device count, the acceptable error rate, the reliability of devices, and the cost and maintenance commitment by users (e.g., collars vs ear tags and LoRa base stations vs. direct-to-satellite devices), is often necessary. For these reasons, users should consider combining data from multiple GPS devices for improved accuracy.

In certain situations, a higher fix rate or an increased device-to-animal ratio may be required to identify the grazed paddock, particularly for short-duration grazing such as crop feeding. The farming system also influences the required number of devices and fix rate. For instance, farmers who milk twice a day (TAD) and utilise separate night and day paddocks are likely to require more devices or devices with higher fix rates to identify the grazed paddocks compared to farmers who milk once a day (OAD) and utilise 24-hour grazing since cows spend less time grazing each paddock.

The farming system also impacts the algorithm for identifying grazed paddocks using GPS devices. For TAD farmers or those farmers who utilise crops or feed pads regularly, the farm area with the most GPS observations must be identified more often and based on shorter periods for the data, which may require a more advanced method than a simple count of points per day or between milkings. Ongoing research is necessary to develop an algorithm that can be applied across the dairy season to identify grazed areas, especially due to an increase in the use of alternative milking frequencies throughout the season, such as TAD, OAD, or 3 in 2 (three milkings every two days) as shown by Eastwood et al. (2024).

Another critical aspect for identifying the paddocks grazed through GPS devices is ensuring the availability of an accurate and up-to-date georeferenced property map. This is illustrated by Farm A's findings, where approximately one-third of GPS observations occurred in undefined areas within the farm boundaries when using the original map supplied by a third party. When using an alternative map provided by a different third party, this number decreased to 6% of total GPS observations recorded due to better paddock outline accuracy.

Unlike previous studies (Hofmann et al. 2022; Hofmann et al. 2023), the current study did not require an on-farm base station, as the devices reported directly to satellites. However, while this approach reduced the time and cost of maintaining base stations, additional fees may exist. For example, the ear tags in this study had a higher per-tag cost compared to previous ear tags used in studies where base stations were required. Additionally, extra devices may be necessary to identify the grazed paddock accurately. This is because the current devices require more battery power to communicate GPS data to the satellite rather than a base station. This limitation reduces the number of fixes achievable under New Zealand conditions, especially with solar-powered devices.

Due to their functions (e.g., the presence of GPS, accelerometer and satellite communication), sensor ear tags such as the GSatSolar and Ceres Trace are larger and heavier than traditional type ear tags (Gobbo Oliveira Erünlü et al. 2023). This study, as well as previous research (Hofmann 2022; Hofmann et al. 2023), has shown that ear tags attached with a single-pin system (e.g., GSatSolar) have lower retention rates compared to those using a twin-pin design (e.g., Ceres Trace), especially in situations where cows have frequent close contact, such as regular use of feed pads or sheltering under trees during the summer months or adverse weather conditions. In such cases, farmers may find it advantageous to opt for ear tags with a twin-pin attachment system when possible. However, a study conducted in Switzerland by Gobbo Oliveira Erünlü et al. (2023) revealed that twin-pin ear tags were associated with a higher risk of causing accidental injuries, infections, and tag migration within the ear, particularly for younger stock, such as newborns. However, this study was conducted in animal housing systems commonly used in Switzerland, so results could differ for grazing systems. As such, further research is warranted to investigate potential animal welfare issues associated with using twin-pin devices, especially in pasture-based systems managing different age classes of livestock.

Conclusions

Accurately recording grazed paddocks provides essential insights into pasture performance, potentially highlighting which paddocks yield more forage. This study has established the potential of using GPS devices but also demonstrates some challenges that still confront practitioners when utilising this technology on-farm. Nevertheless, this technology has the potential to capture grazing information automatically and provide detailed, paddock-specific information, which is invaluable for effective grazing management. This information could guide decisions on rotation length, prioritising grazing areas, and making informed choices regarding pasture renewal and fertiliser usage.

GPS technology can automate the data collection process and alleviate the administrative burden associated with manual recording whilst providing valuable insights into grazing patterns and aiding decision-making for farmers. Further research and development efforts are necessary to optimise the usability, accuracy, and scalability of off-the-shelf GPS devices for on-farm applications and develop a value proposition for farmers.

Critical considerations in the choice of devices include device design, device weight, battery life, solar rechargeability, tag attachment (e.g., single-pin vs. twin-pin) as well as overall tag retention, cost per device, device accuracy, reporting frequency and consistency, plus requirements for data retrieval method (e.g., base station vs. direct-to-satellite). Collaboration between researchers, technology developers, agricultural practitioners and farmers will be essential in refining these tools to meet the needs and challenges of the farming community. The use of GPS automation represents a promising avenue for recording grazing data to enhance the resilience and productivity of New Zealand agricultural systems.

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