Pasture performance tools: current and future state

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Highlights

- Measuring pasture mass informs pasture management for optimal utilisation.
- Traditional techniques for measuring pasture performance are time-consuming and costly. Emerging pasture performance tools were assessed for accuracy, availability (of the tool and of data collected) and limitations.
- Considerable efforts have been made with new tools to reduce the time and effort required to measure pasture performance. Limitations of accuracy remain, associated with calibration methods used in development.
- Promising future technologies will require greater ground truthing for validation and incorporation of multiple data sources.

Keywords dry matter yield, measurement, technology

Background

A key driver of the profitability of livestock farming in New Zealand (NZ) is the utilisation of pasture grown on-farm (Neal and Roche 2020; Caradus et al. 2023). Neal and Roche (2020) suggested that each additional tonne of pasture harvested increases net operating profit of a dairy farm by $300 per hectare per year. Accurate and timely information on pasture yield allows farmers to make informed decisions and maximise pasture harvested. Paddock and farm-scale data enable decisions on grazing rotation lengths, pasture renewal, supplementary feeding, feed conservation and fertiliser use, allowing animals to be well-fed throughout the year (Dalley et al. 2009).

Pasture performance includes aspects related to herbage mass, nutritive value, botanical composition and persistence. However, pasture mass is often considered one of the most important components of pasture performance as it is indicative of the pasture harvest potential. Traditional techniques, such as using a rising plate meter for estimating pasture mass are time consuming and costly in terms of labour and, in some cases, capital. In a survey of over 500 NZ dairy farmers, Dela Rue and Eastwood (2023) reported that 10% of farmers do not measure pasture across the whole farm during spring, while over 50% of the farmers surveyed used visual estimation to assess pasture mass in spring. Dalley et al. (2009) and Eastwood and Dela Rue (2017) also identified that the demands on farmers during spring, namely due to calving and mating, meant that measuring pasture mass at this time was difficult and created a conflict in priorities. Development of new tools for accurately assessing pasture performance in a fast, easy, and reliable way, and at scale, may enable more widespread data collection leading to improved decision making and increased pasture harvested.

In this paper we describe the traditional tools for estimating pasture mass and assess emerging tools, available or close-to-market in NZ as of April 2024. A literature review was conducted, including information from technology-provider websites, which was augmented by short interviews with technology developers and providers. Emerging pasture performance tools were assessed for accuracy, availability of the tool and of data collected, calibrations used in development and limitations. While some of these methods are used in plant breeding and development, the scope of the paper is tools used for either farm-scale research or on-farm.

Traditional tools

(1) Visual assessment of pasture mass is the most common method for assessing pasture performance, with 54% of NZ dairy farmers reporting visual estimate to be their main technique for assessing pasture mass in spring (Eastwood et al. 2020; Dela Rue and Eastwood 2023). Visual assessment of pasture mass involves a person observing a pasture and estimating the average mass of herbage dry matter (DM) to ground level within a given area at several positions in a paddock (Murphy et al. 2021b). It is a non-destructive method which takes into account plant height, density and DM content. Visual assessment of pasture mass can be highly subjective with large variations between observers (± 980 kg DM/ha), depending on operator experience and frequency of calibration (L'Huillier and Thomson 1988; Thomson et al. 1997), and data is rarely recorded (Eastwood et al. 2009).
(2) The Rising Plate Meter (RPM) converts compressed sward height into pasture mass using seasonal calibration equations specific to pasture type (Gargiulo et al. 2020). It is utilised by 22% of dairy farmers in NZ (Dela Rue and Eastwood 2023). Limitations of using a RPM include considerable susceptibility to operator variability and bias when using the tool, inaccuracy

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of readings and time required to walk the paddock (Murphy et al. 2021b). A range of measurement errors have been reported for the RPM, from 311 kg DM/ha, up to 1566 kg DM/ha (L'Huillier and Thomson 1988; King et al. 2010; Wigley et al. 2019; De Alckmin et al. 2020; Murphy et al. 2021a). A recent development in RPM technology led to a modified version, which uses a micro-sonic sensor to estimate the compressed sward height. This has been shown to improve accuracy relative to a traditional RPM, by shifting from a under-estimation of pasture mass of 13.7% (from a traditional RPM), to an over-estimation of pasture mass of 0.3% (McSweeney et al. 2019).

(3) The Pasture Meter, sold by C-Dax, estimates pasture height using an electronic device towed behind a vehicle. The device uses a series of interrupted light beams and high-speed electronic sensors to measure pasture height, and converts average height to pasture mass using seasonal calibration equations (Dalley et al. 2009). The Pasture Meter was developed at Massey University's Centre for Precision Agriculture (Hofmann 2022) and is the second most common tool used to measure pasture performance. It is used by 9% of dairy farmers in NZ (Dela Rue and Eastwood 2023). Pasture Meter measurements are largely independent of the operator and subsequently less prone to operator variability, although measurement errors up to ± 668 kg DM/ha have still been reported (King et al. 2010). The C-Dax Pasture Meter has been calibrated for a range of species, including perennial ryegrass (*Lolium perenne*)/ white clover (*Trifolium repens*) mixtures (King et al. 2010) and kikuyu (*Pennisetum clandestinum*) (Rennie et al. 2009).

(4) Other traditional tools for measuring pasture performance include sward sticks and capacitance probes. Two forms of sward sticks are available to measure pasture yield. The Hill Farm Research Organization (HFRO) sward stick measures pasture height with a 2 cm^2 Perspex cursor which is lowered down a graduated shaft until first contact with green leaf (Hutchings 1991). There is also a simpler tool, also referred to as a sward stick, which is a piece of waterproof card with height markings and conversions to pasture mass (kg DM/ha) for each height (Hofmann 2022). This sward stick was developed by Beef + Lamb NZ and Farmax and includes seasonal yield conversions. The accuracy of the sward stick is influenced by factors such as sward structure and composition, user variability, number of readings taken per paddock and DM content of the herbage. Murphy et al. (1995) reported a correlation with quadrat cut measurements (pre-grazing) of 0.70 for the HFRO sward stick, while no data are available on the accuracy of the Beef + Lamb NZ sward stick. The electronic capacitance probe is a single-probe, electronic device with data collection, storage and calculation capabilities (Sanderson et al. 2001). The probe relies on differences in dielectric constants between air and herbage to measure the capacitance of the air-herbage mixture, thus indicating surface area of the herbage. Like the RPM and sward stick, the capacitance probe requires the user to walk across pastures and is prone to user variability. The reported accuracy of the capacitance probe varies in literature; correlations with quadrat cut measurements taken pre-grazing range from 0.14–0.65 (Murphy et al. 1995; Sanderson et al. 2001).

Emerging tools

The past decade has seen an increased focus on the development and use of precision technologies in agriculture. While some of the emerging tools outlined in this section offer value to a farmer beyond measuring pasture performance, e.g., the decision support and software provided by Pasture.io™, AIMER Vision™ and Halter Pasture Pro™ with features such as suggested paddocks to graze based on estimated pasture mass and projected pasture mass surplus/deficit, this paper focuses solely on their pasture measurement capability.

(1) Satellite-based sensing technology

Reflective characteristics differ between materials and these differences can be used to construct an index that correlates with pasture mass (Tucker 1979). Plants absorb red wavelengths and reflect near infra-red (NIR) wavelengths of the electromagnetic spectrum. The Normalised Difference Vegetation Index (NDVI) measures the ratio of NIR to red wavelengths. Green leaves have higher reflectance in the NIR range than the red range, whereas dead leaves and bare soil have less. Therefore, a high NDVI reading corresponds to a higher level of green, dense pasture mass (Wagenaar and de Ridder 1986; Clark et al. 2006). The NDVI has an upper limit of 1., Near this point most light is intercepted and the prediction accuracy of pasture mass deteriorates. This saturation point occurs in pastures at approximately 2,500–3,000 kg DM/ha, meaning that NDVI measurements are not accurate at pasture mass beyond this level (Wagenaar and de Ridder 1986). Satellite imagery can be analysed using NDVI, providing an estimate of pasture mass.

While satellite-based measurements allow farmers to collect pasture mass data with minimal time and labour and with no risk of operator error during measurement, there are several limitations to this tool. Cloud cover can interfere with the ability of the satellite to take images, alongside challenges posed by atmospheric conditions, variation in pasture mass and species within the pasture (Gargiulo et al. 2020) . Background soil effects and dead material in the pasture also interfere with the accuracy of the tool, as a change in the ratio of photosynthetically to non-photosynthetically active material within a pasture impacts spectral absorption (Murphy et al. 2021b). Livestock Improvement Corporation (LIC, Hamilton NZ) offers a subscription service that provides pasture measurements through a satellite technology called SPACE™ (Satellite Pasture And Cover Evaluation) (Hofmann 2022). This technology utilises NDVI based on imagery from over 100 satellites from Planet Labs™ and two Sentinel-2™ satellites, as well as modelled data from Pasture Vibe to provide an estimate of pasture mass at a 3-m resolution. While these satellites may image the planet daily, interference from cloud cover and satellite positioning may mean that data are provided infrequently at up to weekly intervals (Macdonald 2017; LIC 2023). Anderson and McNaughton (2018) reported an accuracy of ± 329-335 kg DM/ha for the LIC SPACE™ technology when compared with on-farm data measured *via* RPM from 20 Canterbury farms.

Pasture.io™ uses a combination of satellite-based imagery, weather data, individual farm records (including either manual or automatically recorded grazing dates, fertiliser and pesticide applications, mechanical pasture harvests and new sowings) and Artificial Intelligence (AI) to provide an estimate of pasture mass (Pasture.io 2023). Pasture.io™ utilises a model with approximately 30 indices (in addition to NDVI) to learn each paddock's pasture mass characteristics and understand seasonality. Data are available 24 hours after a satellite flyover, which contributes to a rolling 14-day average of pasture mass provided by the web-based platform. Pasture.io™ claims accuracy of pasture mass measurements to be within 20 kg DM/ha of RPM measurements (Pasture.io 2023). No further information on the accuracy or calibration technique for this tool was available at the time of authorship.

(2) AIMER Vision™

AIMER™ is an app-based, digital farming assistant developed by Aimer Farming (Aimer Farming 2023). Aimer Farming has developed an additional technology, AIMER Vision™, which when used in conjunction with the AIMER™ digital assistant, can estimate the pasture mass of a paddock using a camera on a smartphone. To estimate pasture mass, the user stands on the spot and takes an in-app smartphone video in a near-full circle. For Waikato-based perennial ryegrass-dominant pastures, AIMER Vision™ has been determined (by Aimer Farming) to be accurate to within ± 200 kg DM/ha of the pasture mass estimated by other devices such as a RPM in 80% of estimates (J. Bryant, personal communication, October 26, 2023). A claimed benefit of the AIMER Vision™ technology is its ease of use, requiring minimal training to operate (Aimer Farming 2023). The user is, however, required to be within a paddock to record a video (i.e., a video cannot be taken from the edge of a paddock), increasing the time required to measure a pasture. Key limitations of AIMER Vision™ are that inaccuracy increases with greater weed content in a pasture, as the technology cannot distinguish between pasture and weed species, and currently the technology is only applicable to perennial ryegrass/white clover pastures (J. Bryant, personal communication, October 26, 2023). At the time of writing, AIMER Vision™ was only available in the Waikato region.

(3) Halter Pasture Pro™

Halter Pasture Pro™ is part of the Halter smart collar system. Halter collars are solar powered, Global Positioning System (GPS) collars that provide real time cow position, virtual herding and fencing, animal health and behaviour insights, as well as pasture information and planning tools (Halter 2023). The Halter Pasture Pro™ AI model provides automatic daily pasture covers and growth rates based on daily satellite imagery, localised weather data, grazing and cow location data derived from the collars, photos of grazing residuals taken by the farmer, and nitrogen applications, amongst other inputs. The model uses these inputs to estimate pasture mass and growth rates at a 3 m × 3 m granularity across the farm (S. Crowhurst, personal communication, April 10, 2024). No further information on the accuracy and calibration technique of this tool was available at the time of authorship. The prerequisite for the technology is that it requires the farmer to be an existing user of the Halter smart collar system. Pasture data are immediately accessible to the user on their smartphone.

(4) Farmote™

The Farmote™ system combines multispectral images from satellites with pasture measurements from remote static devices, called motes (Milsom et al. 2019). Five-to-seven solar-powered motes are placed in selected locations across the farm and transmit NIR light, measuring the 'time of flight' after reflection off pasture. One mote reads in a 4-m radius (R. Barton, personal communication, November 16, 2023), taking multiple readings between 0100 and 0300 hours, enabling the calculation of pasture growth rate through changes in average pasture height from the previous night (Milsom et al. 2019). The technology then cross-references the measurements from the motes with multispectral images taken from satellites, and the data are run through a proprietary index and calibration equation to provide daily pasture mass measurements (in kg DM/ha) to a web platform accessible by smart phone (Milsom et al. 2019; Farmote Systems 2023). The Farmote™ system also continuously measures atmospheric and soil conditions using sensors within each mote and can accommodate seasonal adjustments to the pasture height-mass calibration. An advantage of the Farmote™ system compared with individual satellite-based sensor readings is the ground truthing of the satellite data, with measurements able to be updated with on-farm data when atmospheric conditions prevent satellite readings. Experiments were conducted in Canterbury to assess the accuracy of the Farmote™ motes to measure pasture yield under real farm conditions using a pure perennial ryegrass pasture and a perennial ryegrass/white clover pasture, with varying varieties of both species (Milsom et al. 2019). The authors reported a strong correlation (R^2 = 0.93) between cut-and-dry pasture yield measurements and the mote estimates in the pure ryegrass pasture. This correlation weakened (R^2 = 0.68) when clover was present in the pasture. The Farmote™ system cannot account for non-height related changes in pasture mass, such as the DM content of the herbage, and is only calibrated for use in perennial ryegrass-based pastures. The presence of weed species can also reduce the accuracy of measurements (Milsom et al. 2019).

(5) Proveye™

Proveye™ is a digital image analysis platform designed in Ireland that can provide detailed insights for biodiversity management and digital monitoring, reporting and verification relating to carbon sequestration and natural assets in grasslands (Proveye 2023). Proveye™ works by aggregating image data from multiple systems and sensor types at different scales, including mobile phones, in-field sensors, an unmanned aerial vehicle (UAV)/drones and satellites. The data are processed using Proveye's AI platform. Forecasted pasture mass is estimated *via* satellite imagery and is available for the next 10–12-day window (P. Kennedy, personal communication, November 22, 2023). Validation of the pasture mass model within Proveye™ has been done using a cut-and-dry method, as well as against RPM data collected across a range of farms in Ireland. When measuring pasture mass (in kg DM/ha), Proveye™ has shown to have 85% ± 5% accuracy relative to cut-and-dry pasture mass, with a 38% reduction in variability when compared with a RPM (when the RPM is calibrated as per manufacturer's instructions). The platform requires no recurring data input from the farmer as grazing events and split paddocks can be automatically detected by the platform's AI. Proveye™ also has the potential to estimate persistence of pasture mass, as it can estimate a change in pasture density over time.

Proveye™ is generally targeted at the multi-farm, enterprise level, e.g., co-operatives and milk supply companies (P. Kennedy, personal communication, November 8, 2023). This could be a limitation of the technology for use in NZ. Proveye™ provides either statistical, or spatial, map-driven insights to the enterprise by an Application Programming Interface (API), and it is up to the enterprise to share data to individual farmers. Proveye was not commercially available in NZ at the time of writing.

(6) Photogrammetry and structure-from-motion

Lincoln Agritech has completed a proof-of-concept study to estimate pasture mass using photogrammetry coupled with structure-from-motion (SFM) (Wigley et al. 2019). Photogrammetry is a remote-sensing technology that extracts relevant data from digital surface models to estimate plant height, while SFM is a method that uses computer vision technology to take overlapping 2D images and create a 3D point cloud. By attaching a digital camera to the back of a vehicle, this combination of methods was used to estimate pasture mass by creating a 3D elevation model of pasture, where height correlates to mass. The pasture mass was calibrated by harvesting and drying samples from within each sampling quadrat, as well as RPM measurements at each point. Wigley et al. (2019) reported that measurements from photogrammetry were more accurate than RPM measurements and NDVI when estimating pasture mass (photogrammetry-derived plant height and actual herbage mass R^2 = 0.92 in May, compared with a R^2 of 0.91 between RPM and actual herbage mass, and 0.65 between NDVI and actual herbage mass, respectively).

The photogrammetry and SFM technology can be used from any platform that can carry the camera, such as a centre pivot. Images can be taken from a consumer-grade camera. If used with a timer, this set-up could automate the remote measurement of pasture mass that is easy, repeatable and cost-efficient, with immediately available data. In photogrammetry, the height of the pasture is subtracted from the ground surface height, so further work is required to develop a suitable reference point to derive pasture height from, as stock do not graze down to ground level (Wigley et al. 2019). Additionally, pasture species composition will affect the relationship between pasture mass and height. Limitations of photogrammetry include sensitivity to variations in lighting conditions, and to wind, as the vegetation surface should be still during photographing. Further, uneven distribution of pasture mass, low plant and/or tiller density and low vegetation cover (such as in newly sown pasture) make it difficult to accurately estimate pasture mass using photogrammetry.

(7) Cow wearables

Recent research has assessed the potential of individual animal sensors to predict paddock-level pasture mass (Edwards et al. 2024). There are a range of animal wearable technologies (sensors) available, many of which use accelerometers to capture animal movement information, which when combined with algorithms, can be classified into behaviours, such as eating, ruminating and activity. The authors demonstrated that post-grazing pasture mass estimated from animal sensors was moderately related to RPM estimates of pasture mass (R^2 = 0.48–0.52). Further work is underway to use GPS data provided by some wearables to create new behaviour classifications (P. Edwards, personal communication, January 29, 2024). When these new behaviours are combined with currently measured behaviours, improved estimations of pre-grazing pasture mass are provided (R^2 >0.6). There is potential for this new algorithm to be commercialised, creating a tool for measuring real-time pasture mass for those farmers who utilise cow wearables and allowing measurements of pasture mass measurements. Dela Rue and Eastwood (2023) reported that 16% of dairy farms are using wearable technology, with more dairy farmers identifying this as a key piece of technology they wish to invest in the next 2 years.

Discussion

It is evident that considerable efforts have been made with new tools to reduce the time and effort required to measure pasture performance. There is variation among the tools in the sourcing of data: some of this is done by the tool itself, some integrate data from different sources, and some require additional manual data input, such as grazing records. It should be noted that the accuracy of some of the tools described in this paper has not been reported in peer-reviewed literature, and some of these tools are still in the early stages of product development, so the accuracy of them is likely to change. While there is a range in the accuracy, availability of data, calibrations and limitations of each tool, across all tools the limitations of accuracy when measuring pasture performance, remain. This is largely associated with calibration methods used in development. Many of the tools have been calibrated using a RPM with a standard equation, which as previously stated, has an inherent measurement error associated. As such, any tool calibrated using this method may be either more, or less accurate than indicated by the RPM, and this should be considered if accuracy is a high priority when selecting a tool to use. The ability to validate tools against more accurate ground truth data, such as either cut-calibrated RPM data, actual cut data, or alternatives such as back calculation of pasture harvested (e.g., Hofmann et al. (2022)), may improve the ability to estimate pasture performance accurately. There may be multiple criteria, however, by which a tool's performance could be measured, including temporal stability and spatial heterogeneity (Nickmilder et al. 2023).

The relative importance of criteria considered when assessing a pasture assessment tool is dependent on the end use of the information (Dalley et al. 2009). For example, if the tool is being used to rank paddocks from highest to lowest pasture mass, then less accuracy is sufficient than if the information is being used for pasture allocation to livestock. When considering the minimum acceptable performance metrics for a pasture measurement technology, Eastwood and Dela Rue (2017) reported that data availability ≤ 24 hours and ease of use were more important than accuracy of data (± 200 kg DM/ha), although in the context of pasture allocation decisions, an accuracy of ± 10% was required.

Satellite-based sensor data that may improve estimations of pasture performance will become more available, in terms of variety of sensor, more frequent temporal resolution and higher spatial resolution. Promising developments include hyperspectral sensors with more bands of data and radar-based sensors able to provide data when cloudy.

Data fusion, which aims to improve accuracy and consistency through the integration of multiple data sources, is another promising approach. For example, Nickmilder et al. (2023) combined satellite data from Sentinel-1™ (radar), Sentinel-2™ (optical) and meteorological data to predict RPM measurements of pasture mass. Additional farm data, such as grazing dates, are likely to be useful and may be automated with GPS-based wearables (Hofmann et al. 2024).

Conclusions

Tools that can be proven to reliably estimate pasture performance at scale will benefit NZ farmers by providing them with a reliable measure of pasture performance on-farm. Considerable efforts have been made in the development of new tools that address the key limitations of conventional tools, namely the time and labour required for measurement. However, limitations around achieving sufficient accuracy for on-farm use are yet to be overcome. Available tools primarily measure pasture mass only, from which pasture growth or yield can be derived. Thus, there remains a need for a tool that can estimate pasture quality, botanical composition and persistence. Developments in the availability of satellite data and wearable data, in combination with data fusion techniques and the ability to validate measurements more effectively, give some hope that pasture performance can be estimated more accurately, and so contribute to the competitiveness of the pastoral sector.

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