# Assessing the ability of a stationary pasture height sensing device to estimate pasture growth and biomass

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## Abstract

Good pasture management requires an accurate knowledge of whole-farm feedbase, yet most systems for measuring pasture growth are manually operated and time consuming. A newly developed pasture-measuring device enables remote measurement of pasture height on a regular basis. This study investigated the accuracy of such a device compared with a rising plate meter, then assessed the device on a pure perennial ryegrass paddock at a research farm, followed by field testing in a perennial ryegrass/white clover paddock on a commercial dairy farm. A strong correlation ($R^2$ = 0.93) was obtained between collected DM yield and device-derived pasture height within the pure perennial ryegrass paddock but the correlation was weaker ($R^2$ =0.68) with data from the dairy farm perennial ryegrass/ white clover paddock. There is considerable potential to improve upon these initial data through the use of adjusted calibrations. Findings demonstrate the device has the potential to accurately estimate pasture growth.

**Keywords:** feed wedge, pasture management, remote monitoring

## Introduction

Rotational grazing management decisions, based around time of grazing and pasture sward regrowth intervals, strongly influence dairy farm productivity. Therefore, regular assessment of pasture cover is crucial if pasture utilisation is to be optimised. Combining assessment with appropriate management tools (e.g. feed wedge, spring and autumn rotations) provides vital information for pasture managers. Accurate and timely pasture information is vital to identify surpluses and deficits, and better match pasture with herd demand. Beukes et al. (2015) found that farm operating profit could increase by approximately $385/ha when pasture cover per paddock is known with an average error of 15% compared to when pasture cover per paddock is not known. The most direct estimation of pasture mass is obtained by cutting and weighing pasture from an area of paddock. However, this is a labour-intensive process so a number of more efficient alternatives have been, and continue to be, developed such as calibrated eye assessments, hand-held devices, e.g. the Rising Plate Meter (RPM), or mobile devices attached to a vehicle e.g. the C-Dax Pasture Meter (CDM). Many remote systems are also being investigated, e.g. drones, LiDAR, and satellite imagery (Bensemen 2013) but most of these still require labour on farm to move equipment around. Only satellite imagery is truly remote but it is unfortunately intermittent and, although relatively accurate, is poorly correlated to actual biomass (Asher et al. 2018; Bensemen 2013).

One recently developed system (Farmote) uses remote static devices to capture pasture measurements and soil conditions, which can then be cross-referenced with multispectral images taken by satellites to provide whole paddock estimations of biomass. Measurements of pasture height are collected nightly. These data enable pasture growth rate (change in average height) to be calculated. The system is solar powered and measurements are transmitted via radio to an accessible web portal. The data can be correlated to biomass and a calibration equation used to provide an estimate of pasture dry matter (DM). This system also has the potential to measure soil and atmospheric conditions, and accommodate seasonal or other adjustments to improve the accuracy of the calibration and thus yield calculations. Although the sensors are static, the remote collection of data means that this system is less labour intensive than hand-held (RPM), mobile (CDM), or many remote (e.g. drones) technologies that require labour to walk, drive, or operate equipment in the paddock being measured. However, in order for the device to be a useful tool, it must be able to estimate pasture mass accurately. This study aimed to develop an appropriate protocol to test the ability of the devices to estimate DM (by comparing data from the devices with cut derived dry weight), then use this protocol on a dairy farm situation to better understand the potential of the device to assess DM under real farm conditions.

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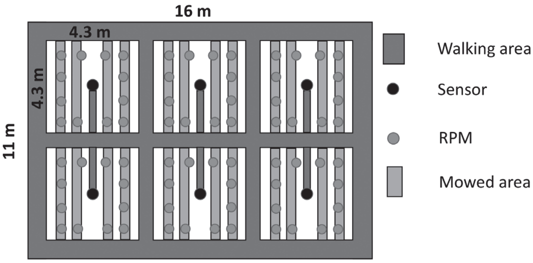


**Figure 1** Layout of Farmote device (sensor) testing stations and location of rising plate meter readings for preliminary investigations at the Lincoln University Research Dairy Farm.

## Materials and Methods

An integrated experiment was conducted over successive time periods to compare device readings with sward biomass to create a calibration equation for the Farmote device in perennial ryegrass-dominant pastures. Preliminary investigations (September 2018 – January 2019) and development of a calibration protocol (February 2019), were followed by an on-farm assessment of Farmote devices for estimating DM (March 2019).

**Farmote Stationary Pasture device** – Farmote devices contain six depth sensors, located at the top of a pole transmitting invisible near-infrared light and measuring its "time of flight" after it reflects off the objects. The system is solar powered and measurements are transmitted via radio to an accessible web portal. Data are collected each night (as the sensor is more accurate in the absence of interfering incident daylight) through multiple readings taken between 1.00 am and 3.00 am and change in pasture height is determined by subtraction of data from the previous night sward reading from the current data.

***Preliminary investigations*** – A preliminary investigation to assess the accuracy of Farmote devices was conducted at the Lincoln University Research Dairy Farm (LURDF). In September 2018, three testing stations were established inside 1.5-ha paddocks. Six prototype devices (2 × 3 units) per station were installed within fenced-off areas (11 × 16 m) that were representative of the pasture cover (botanical composition and yield) within the chosen 1.5 ha paddock (Figure 1).

Since establishment in 2015, these pastures of perennial ryegrass (*Lolium perenne*) cvs. AberMagic and Prospect, and white clover (*Trifolium repens*) cv. Kopu II were grazed with dairy cattle. During the experiment, simulated paddock grazing events were conducted according to pasture growth and feed demand as normal practice of LURDF. Pasture biomass was harvested in October, November and December 2018, and January 2019, at each respective testing station, mimicking the 10 dairy grazing events throughout spring and summer until January 2019. These grazing events were simulated by mowing monitor areas on 7, 11 and 18 October, 11, 15 and 22 November, 5, 6 and 21 December 2018, and 8 January 2019. For this purpose, four strips (0.4 × 4.3 m) across the coverage area (4.3 × 4.3 m) of each device were mown to a height of 4.6 cm. The devices were left *in situ* during mowing. Herbage DM yield was calculated at each defoliation event by obtaining fresh herbage harvest weight and DM% determination of an oven-dried (70°C) subsample from each device coverage area. During this period, pasture height was measured each night using Farmote devices. Additionally, herbage growth was monitored weekly with RPM readings at 12 different locations within each monitor site for each device (Figure 1) using one Jenquip electronic plate meter which was calibrated at the start of the preliminary investigations in October, by plotting a linear regression of the RPM readings against the actual pasture herbage mass harvested from initial mowing of the monitor sites. Dry Matter yield data was plotted against pasture profile height readings obtained from the devices to generate a regression equation to determine the overall accuracy of the devices, which calculate change in pasture height by subtracting the previous sward readings (from 24 hours before) from current sward profile height readings.

***Calibration protocol – Experiment 1*** A 10-ha paddock planted with perennial ryegrass (*Lolium perenne*) cv. Alto in October 2018 at Barenbrug Agriseeds' plant breeding station was used. The soil was a Templeton silt loam, which is a type of Typic Immature Pallic Soil (Udic Haplustept, USDA Soil Taxonomy). Three areas with different ryegrass heights were identified across the paddock using a metre ruler; medium (10–15 cm), long (18–26 cm), and very long (18–40 cm). A fourth area was cut to simulate a short (3–6 cm) pasture height. Ten (4 × 4 m) plots were created in each of these areas (Figure 2). On the 12 December 2018, one device was placed in the centre of each medium-height plot. Grass height was recorded by the device overnight and the whole plots were mown to a height of 4.60 cm the following day between 10:30 and 12:30 am. The devices were removed before mowing and put back in the same position afterwards. Dry matter was collected and processed as above to determine the DM yield per hectare in each plot. The devices were left in the same plots for a second night in order to record the post-cut height before being moved to the next set of 10 plots of a different height. This process was repeated until each set of ten plots had been measured.

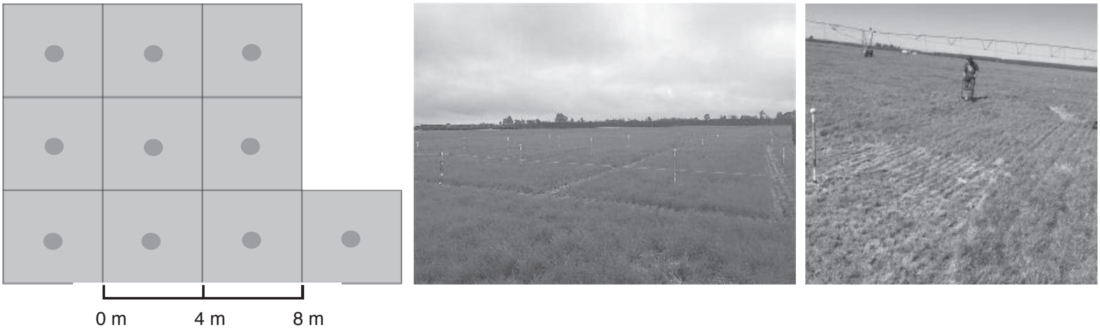


**Figure 2** Design of trial plots used in Experiment 1 (left), and medium height plots (centre), Experiment 2 being cut (right).

Height measurements determined by the devices were plotted against harvested DM yield/ha to determine the accuracy of the device.

Experiment 1 was extended with a fifth cut, after the paddock had been cut for silage in order to obtain additional data for DM in the range of 1000 to 2000 kg/ha and pasture height of 6–10 cm. A new set of 30 (4 × 4 m) plots containing grass (3–6 cm) was set up on 24 February 2019. The plots were arranged as a 3 plot × 10 plot grid and had ten devices placed in one row at the beginning. Two plots were mown each day to a height of 4.6 cm and the devices from those plots moved to new plots after one night post cutting. The DM% was calculated and plotted against the height recorded as above.

***On farm assessment** – **Experiment 2*** This experiment was conducted in a perennial ryegrass (Trojan)/white clover (Weka and Kotuku) pasture irrigated by a centre pivot on a dairy farm on Telegraph Rd, near Darfield, Canterbury (-43.516070, 172.132059). The soil was a Pallic orthic Brown Soil (Typic Dystrustept, USDA Soil Taxonomy). On 26 March 2019, ten devices were placed approximately 10 m apart in a line. Devices were left overnight to record data. Experimental design was simplified by geometrically marking a 4 × 4 m square within a circumference using the device as the central point. Thus, devices could be placed randomly in the field and a square around each device could be easily marked and cut. The area was cut with a lawn mower at a height of 4.6 cm with the devices being removed prior to mowing and put back in position afterwards. Dry matter weight was calculated as above. Devices were left for a second night to record post-cut height and then moved to an adjacent paddock (-43.515480, 172.134237) and the process repeated. A third set of readings was recorded by moving all devices approximately 10 m to the east in the second paddock and waiting one week before repeating the measurement process.

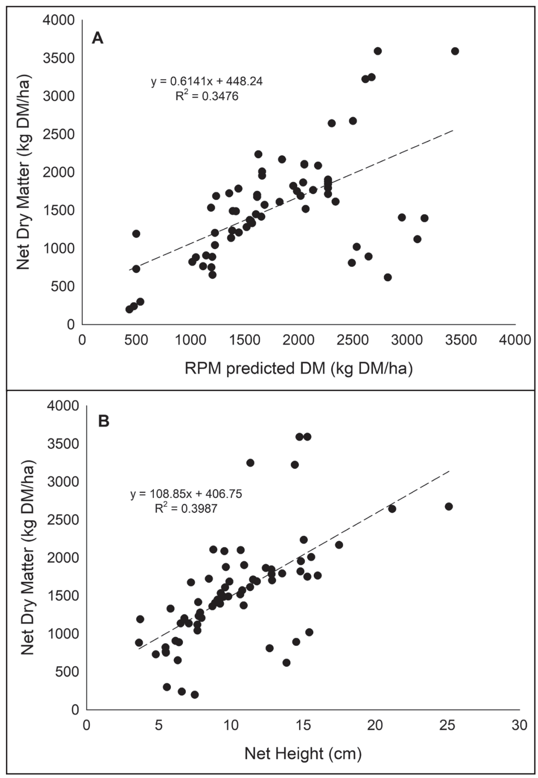


**Figure 3** Relationship between net pasture DM (kg DM/ha) and (A) Rising Plate Meter-estimated DM and (B) device-measured height (cm), from September 2018 to January 2019 preliminary investigations at the Lincoln University Research Dairy Farm.

***Interpretation of sensor data*** The sensor data were processed by first using proprietary algorithms and then data were averaged to give a single reading for each device or plot. The change in height was calculated taking the average reading obtained the night following the mowing of the plots and subtracting the average reading from that of the previous night. These net height differences were then plotted against the dry matter calculated.

## Results

***Preliminary investigations*** The correlation for the regression between actual DM yield and RPM-estimated DM yield was low ($R^2 = 0.35$; Figure 3a). The linear regression produced from DM yield and device-derived pasture heights also showed a weak correlation for pasture profile height ($R^2 = 0.40$; Figure 3b).

***Experiment 1*** DM yield was plotted against device-derived pasture height for all four pasture height categories (Figure 4) and a strong correlation was obtained for the first four cuts ($R^2 = 0.93$).

Data from the additional part of Experiment 1 (fifth cut undertaken after the silage cut) were added to the original data set (Figure 4 grey circles). The DM yields (1000–2000 kg DM/ha) were higher than those of the first low cut but the device measured change in grass height was similar for both cuts. Thus, there was a discrepancy in the correlation of net DM and change in grass height between the two different time points, and the overall correlation (for all 5 cuts) dropped to $R^2 = 0.91$.

***Experiment 2*** A number of issues occurred *in situ* in Experiment 2 so minor refinements were made during the experiment to try and remedy the issues. After cut one, a device fell over before it measured the height of the grass and, for three other devices, the lawnmower height was knocked and accidently cut too low. The data from these four devices were discarded as outliers. Between readings 1 and 2, the area cut was reduced to 3.6 × 3.6 m to more accurately reflect the area measured by each device and it was also noted that the stony ground compromised the vertical stability of the devices. Devices were modified between readings 2 and 3, with addition of a central rod from the base which could be inserted into a pre-drilled hole in the paddock to prevent instability. One device stopped working for cuts 2 and 3; and two devices could not be re-positioned correctly post cut as dirt/stones had fallen into the pre-drilled hole, making accurate replacement of the device impossible. Due to these issues, data from one device in cut 2 were discarded and data from three devices in cut 3 were discarded. The remaining data from cuts 1, 2 and 3 were plotted against net dry matter per hectare (Figure 5) and a moderately strong correlation was obtained ($R^2 = 0.68$).

## Discussion

Despite pasture height data being collected nightly from the Farmote devices over the 5 months of preliminary investigation, there was a poor correlation with collected dry matter over the same period during the preliminary investigations. Possible reasons include extrapolation from sensors that were measured to ones that were not, only cutting part of the area within the sensor detection zone, and changes to data collection frequency. It is also possible that temporal changes (over the 5 months) in pasture were not accounted for and the system may need seasonal calibration.

There was also a poor correlation between collected dry matter and the RPM readings (0.35). Correlations between RPM height and pasture mass have been found to be between 0.69 (Roche et al. 2005) and 0.84 (L'Huillier et al. 1988). However, Lile et al. (2001) suggest that 50 readings per paddock are required to be accurate. Although 12 readings per monitor area (18.5 $m^2$) were taken with the RPM, only a single calibration of the RPM used was done at the start of the trial, which may have contributed to the poor correlation observed. Additionally, pasture botanical composition dynamics from October to January may have reduced RPM accuracy, as broadleaf weed and white clover content were visually more apparent within monitor areas into December and January. It should also be noted that this preliminary work was not always undertaken by the same operator, and the operators were inexperienced in RPM use. Seasonally adjusted calibrations are common practice for RPM and CDM devices, and manufacturer-supplied calibrations take into account season and geography (Rennie et al. 2009). For this reason, the calibration experiment (Experiment 1) was designed to run over a short time frame and whole plots were cut and weighed in an attempt to improve accuracy. Dry matter was accurately predicted using devices within a single ryegrass paddock on one farm over the short time frame of Experiment 1. The correlation between DM and device-derived height in this experiment was good compared to published literature for the RPM and CDM, which can have considerable errors in estimating pasture biomass (Rennie et al. 2009). For example, reported CDM correlations range from 0.63 to 0.91 (Hansson 2011; Schori 2015; Yule et al. 2010). Farmote devices may have lost some accuracy as a result of removing and replacing devices between cuts so leaving the devices *in situ* and harvesting around them is being trialled in a separate study. Underestimation of DM by the devices following a silage cut in Experiment 1 indicated that dry matter estimation requires more than just height and density to be accurate under different conditions. It was noted that the post-silage cut data were obtained within a period of dry conditions where only little pasture growth occurred. This may have caused the devices to underestimate DM since a lack of soil moisture has been shown to increase pasture DM% (Levy 1970). The devices cannot currently account for such non-height related changes. Additional information such as weather, season, soil moisture and geography can all be used to provide calibration adjustments and, as such, future calculations should be

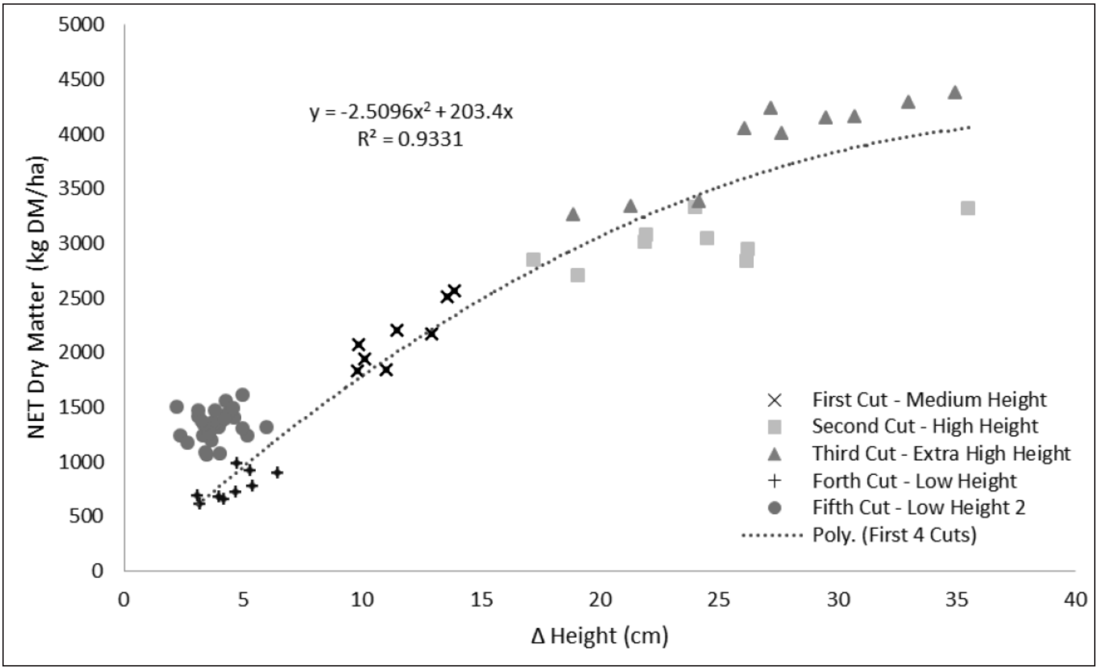


**Figure 4** Relationship between the device-measured change in height (Δ Height) and net DM for Experiment 1.

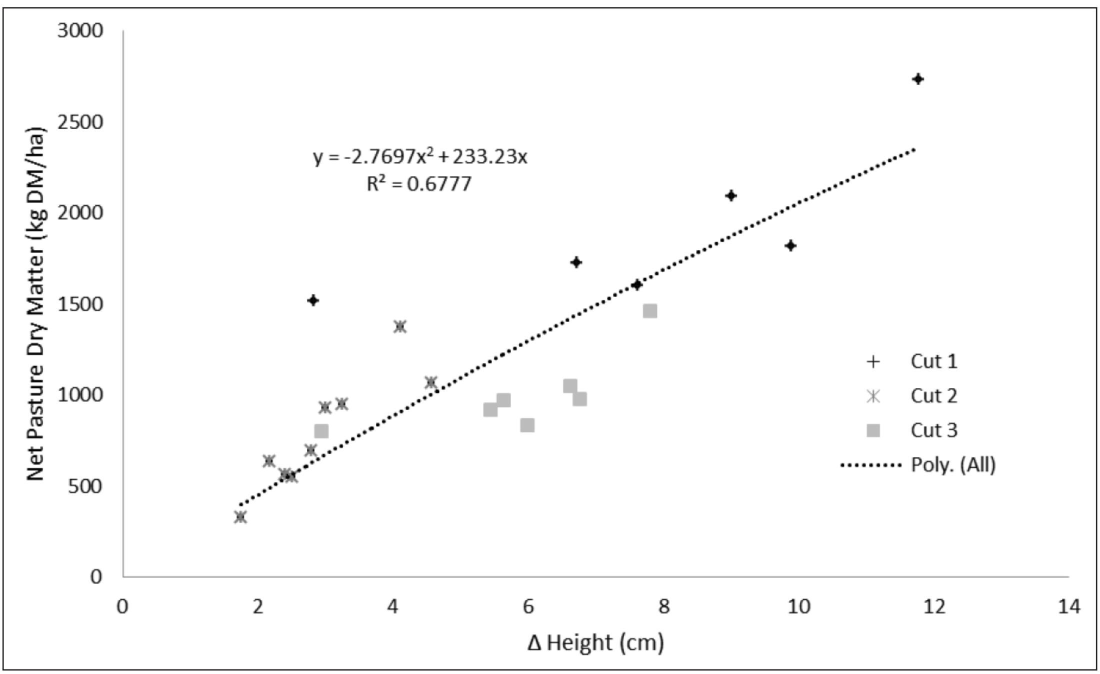


**Figure 5** Data from Experiment 2 showing change in device measured change in height (Δ Height) vs net dry matter per hectare in each plot.

able to account for the discrepancy seen above.

Experiment 2 was conducted on a commercial farm and a number of operational issues occurred (such as devices falling over, failing, or unable to be re-installed after mowing). These issues highlighted practical problems of the current system and affected the quality of the data produced. Other factors that may have reduced the accuracy of the correlation include the mixed nature of the sward and the presence of weed species; also the topography was more uneven than in the pure ryegrass paddock. Despite these possible issues, the initial applied correlation was still similar to those from either RPM or CDM, at an accuracy of $R^2 = 0.68$. Farmote is planning to equip the devices with moisture probes so that soil moisture can be factored into the equation. More stable devices are planned, and calibration experiments that do not require the devices to be removed and replaced are underway. The commercial devices have a spring near the base, which enables them to return to vertical if pushed by livestock, as well as spines on the sensor to deter inquisitive cattle. Although Experiment 1 highlighted the potential accuracy of the device it also highlighted the issue of static devices in that each device only measures one small part of the paddock. Thus any one, or few, sensors in the paddock used in Experiment 1 would not accurately measure the whole paddock as it contained regions of medium, long and very long grass. To overcome this limitation, it is planned that the devices will work as sentinels alongside satellite information so that the relatively accurate satellite data can be calibrated by the sentinel. On occasion when satellite information is missing then estimations can be imputed from previous information. This approach means that only a few devices per farm should be required to calculate whole-farm biomass.

Additional experiments in Europe, Australia and New Zealand are underway and aim to rectify the issues highlighted in these initial experiments.

## Conclusions/Practical implications/Relevance

The devices were at least as accurate at estimating DM as a RPM. Furthermore the ‘fix and walk away’ concept offers strategic advantages over other systems, e.g. labour saving, time saving, and use in remote locations. The ease of receiving a simple, current, feed wedge on a web portal is also a useful service for pasture managers. Changes in sward height are easily calculated from data collected on consecutive nights. This approach has several advantages over mobile visual, spectral, or LiDAR devices that have much more complex operating and data requirements, and complex processing pipelines. They first have to identify and match the area to be measured and then calculate the day-to-day differences, adjusting for factors such as light, wind, speed, height to calculate the change in a particular area under investigation (potentially using 3D point cloud surveying). Such systems may be overly complex and not suitable for on-farm situations, which require simple systems that can be operated and managed in a timely fashion. The disadvantage of the devices are that they measure only a defined area of a paddock and do not account for within-paddock variability. Even if the data can be used to calibrate satellite information, such information is not regularly available so prediction across paddocks will still be required at certain times. The devices are still being tested and issues regarding stability and functionality are still being identified and rectified. Further work is required to develop a series of calibrations to account for pasture type, temporal changes and environmental effects. Costs to purchase and deploy a large number of sensors across a farm may also be an issue.

The device is upgradeable with moisture and temperature probes planned, and potential upgrades to sensors that can provide quality measures. Dairy farmers are required to be more sustainable, and efficiency gains through the supply of timely accurate feed audits will be a major step towards achieving this goal.

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