Pasture and soil monitoring techniques for use with grazing ruminants

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Application Having access to accurate information on pasture quantity and quality attributes is important for successful management of grazing ruminants and efficient pasture production. Understanding soil physical characteristics and fertility levels are also important. All of these have been difficult to measure and characterise to the level of detail required to assist on-farm management in calculating dietary requirements. Recent developments in remote and proximal sensing should make it possible to increase the range, frequency and reliability of pasture measurement, informing the grower of current production and providing a sound basis for forecasting future productivity with greater accuracy.

Introduction Farmers and graziers require information to manage their properties. Attempts to provide pasture yield mapping as early as 1999 failed because that was not what farmers wanted. Dairy farmers for example, were looking to improve their feed budgeting and so required better feed budget information. They were not so concerned with the concepts of precision agriculture and yield mapping at that stage. In recent years there has been a greater desire to quantify nutrient levels in the pasture, again to provide better information around feed budgeting. Soil mapping and the introduction of precision irrigation have had a greater impact in the need for mapping capability. On more extensive systems mapping pasture is complex due of the ever changing species mix, stages of maturity, moisture and nutrient status. In the latest hyperspectral work many of these attributes have been successfully identified creating new possibilities.

Development of pasture monitoring systems The author is one of the co-designers of the C-Dax Pasture Meter which is now on approximately one third of New Zealand dairy farms. The technology provided a means of measuring pasture height which is then calibrated to a pasture dry mass. This provided an auditable method of rapidly measuring pasture cover in the field without the need for specialist skill or knowledge. The system provided an accurate feed wedge, which was what farmers wanted, they did not want pasture mapping at that stage. Techniques to estimate soil moisture holding capacity and status have also been developed and used in conjunction with “Precision or Variable Rate Irrigation”. These techniques have demonstrated considerable savings in water use, leading to reduced costs and nutrient leaching through drainage.
Remote or proximal sensing has also been attempted through the use of optical instruments, multispectral sensors or cameras. In general these methods have not gained sufficient traction to be commercially viable. Pasture is tremendously variable and this creates many difficulties in developing reliable information without significant labour input.
Recent developments in Hyperspectral imaging have proved to be more promising whereby the nutrient concentration, nutrition parameters and species classification can provide a wealth of information. This was primarily developed in New Zealand’s hill country to provide a new method of creating improved soil fertility and nutrient requirement maps. The same principle is now being applied to dairying. In both areas, information from in-ground sensors connected through the Internet of Things can also provide continuous information on soil moisture status and likely growth providing a well-informed platform for pasture production modelling and forecasting. The possibilities of using on-ground roving robotic platforms is being tested in preference to unmanned aerial vehicle- based systems which had been previously researched but considered to be too costly, lacking reliability, had a high level of weather dependence and the quality of information was not an improvement on what was achieved through other means.

Results Results from a programme of work demonstrating the progression of measurement techniques will be given. Earlier work indicates that some farmers have been successful in achieving significantly higher output (milk production), increased pasture production with reduced fertiliser costs through the adoption of some fairly simple precision agriculture techniques. When these have been applied and managed correctly then large improvements in farm performance have been achieved, a case study will be given. Recent developments in the use of hyperspectral imagery will also be demonstrated, this work is being developed and applied to more precisely define soil nutrient status of New Zealand hill country farms. This project (Pioneering to Precision) is jointly funded by Ravensdown Ltd and the Ministry of Primary Industry (NZ).

Conclusion The holy grail of being able to measure pasture quantity and quality is becoming a technological reality. However, we must never lose sight of producer’s requirements for labour saving and low cost. This is an area where adoption has not been high and further development work is required to better understand the needs of the market.

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Prospects for smart soil management techniques in grazing systems – techniques and implications of spatial management of grassland soils

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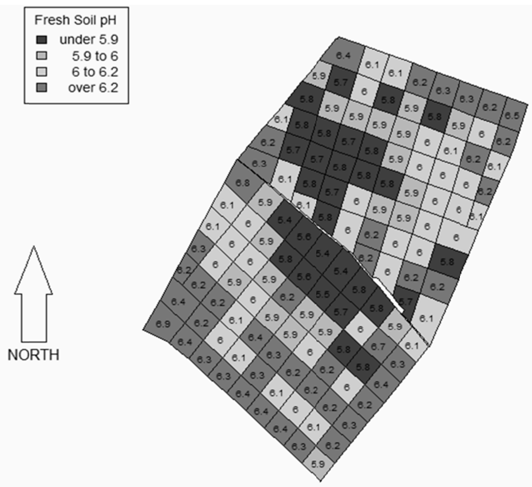
Application Precision management of nutrient input to grazing systems offers the opportunity to optimise pasture production whilst minimising environmental impacts.

Introduction Grazed grasslands are associated with highly heterogeneous soil properties that develop as a consequence of uneven distribution of dung and urine deposition, differences in underlying topography, and variations in soils and microclimates. This heterogeneity leads to variability in plant growth, nutrient usage efficiency, and nutrient (particularly nitrogen) losses. Despite this, it is conventional to manage fields uniformly when adding nutrients or lime leading to inefficient nutrient use. Development of spatially variable inputs to grasslands requires an understanding of the spatial distribution of underlying soil properties, and the way in which they influence soil and plant nutrient cycling. This paper provides an overview of the variations in soil fertility that contributes to uneven nutrient use efficiency, and using the example of variations in soil pH, assesses the extent to which spatially variable applications of lime could be predicted to influence pasture production, and greenhouse gas emissions.

Material and methods Detailed spatial analyses of soil available nitrogen (ammonium and nitrate-N), pH, soil moisture, topography, and nitrous oxide emissions (using static chambers) were carried out on grazed grassland soils at the Bush estate (SE Scotland) over a period of a year. The relationships between the various driving variables and nitrous oxide emissions were explored using a regression analysis. The pH survey demonstrated that some areas of the field on the Bush estate were associated with pH values of <5.5. Using empirical relationships between pH and nitrous oxide emissions, estimates were made on the influence of precision and conventional liming on greenhouse gas emissions and pasture growth.

Results



Soil pH varied between 5.4 and 6.9 across the field. We also observed large variability in soil wetness and nitrous oxide emissions. Two liming strategies were compared, one involving a conventional lime application based on the average soil pH and the other based on precision liming to individual squares within the field. The conventional liming strategy resulted in a uniform application of 4.3 t/ha lime, while the precision treatment received 7.6 t/ha lime targeted at lower pH areas. The implications of these different lime applications on N_2O emissions were predicted from published relationships between soil pH and N_2O emissions (Bouwman *et al.* 2002). For more acidic regions of the field the N_2O emissions were reduced by 18% with precision treatment, but the conventional liming treatment had little effect on direct N_2O emissions. Liming is also recognised to offer benefits in terms of increasing plant available phosphorus, increasing plant biomass production and enhancing carbon sequestration.

Conclusion There is an increasing understanding of the importance of soil properties and processes. This provides an opportunity to develop spatially explicit management in which resource inputs are better matched to soil conditions. The use of such approaches to manipulate nitrogen inputs has so far proved to be challenging, however, precision liming has proved to be more successful. This also supports co-benefits in terms of N_2O mitigation, improved fertility and crop production. Precision nitrogen management will require improved understanding of soil processes and an ability to measure and model spatial distribution of pools and processes.

Acknowledgements We are grateful to Soil Essentials for undertaking the soil pH survey. This work was supported by funding from a Walsh Fellowship and the Scottish Government.

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Tracking and control of livestock in extensive systems

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Introduction All ancestors of domesticated livestock roamed freely. When hunter-gatherers became sedentary, fencing was needed to keep livestock in or out of specific areas. Early husbandry systems also involved herding of animals. Systems which control grazing must be flexible. With increased use of fencing, grazing control became more static. The invention of electric fencing in the 1930s helped to improve flexibility again (Umstatter, 2011). Today, we need to take the next step in the evolution of controlling livestock. That includes developing a tracking system, integrating additional sensors in order to monitor the behaviour and to develop a virtual fencing system. Virtual fencing will truly help us to control and guide our livestock flexibly and so optimise grassland output, decrease labour and costs and minimize impact on the environment. In addition, with free roaming herds, either in non-fenced areas or large extensive systems, such as the Alps, the tracking of cows is very time consuming. The means of choice was the cow bell in the olden days. With new technologies, tracking and data transfer become much easier and new opportunities will arise as part of the digitalization of agriculture.

New technologies for livestock management on grassland – a few thoughts The first step to livestock control on pasture is locating the animal. The most common technology to track animals is the Global Positioning System (GPS). However, transmitting the data can be challenging in e.g. mountainous areas. Often, data transmission is done via the Global System for Mobile Communications (GSM) but there are limits to the system as mobile phone coverage is needed. Moreover, there are costs. In addition, GPS is power hungry and supplying such a system with enough energy to be operational for a whole grazing season can be challenging. If, apart from the energy demand of the GPS, additional energy for data transmission is needed, the system soon could reach its limits.

A new low-cost radio technology with minimum energy requirements and long range might be a good solution to decrease at least the energy demand for data transmission. The LoRaWAN (Long Range Wide Area Network) was developed as an additional network to support the Internet of Things (IoT). If we bring the idea of the IoT into agriculture, we could in future even link up different devices such as a milking robot or an automated herbage measurement device and a virtual fencing system to optimise animal production and maximise the use of grassland (Umstatter et al., 2015).

Following up on the idea of a virtual fence, there are still major challenges to overcome in order to develop a GPS-based virtual fence. Apart from the question of sufficient energy supply, the issue of the animals learning how to deal with the fence is crucial for animal wellbeing. Only, when the cows understand how the system works, will they be able to relax whilst grazing near the fence line. Koene et al. (2016) found that cows were grazing less in a small strip field when fenced with a so-called ‘Invisible Fence’ (Monod et al., 2009) compared to an electric fence. For learning support it is necessary that the timing between crossing the fence line, triggering the warning stimulus as well as the aversive stimulus is correct and the signals are clear to the cow. If this is not guaranteed the system will be either ineffective or threatening to the animals, or both.

Conclusion In conclusion, suitable technologies are increasingly available and provide us with a plethora of opportunities to improve our grazing management. The advantages range from labour savings, to reduced fencing costs or putting the flexibility back into grazing and linking up monitoring and controlling devices. Although not all issues and challenges are yet solved, research will support a rapid development within the next years.

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Precision monitoring systems for the performance and health of grazing livestock: remote and animal-mounted sensors for monitoring the feeding, performance and health of free-ranging animals

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Application Precision tools have the potential to improve the efficiency of the management of grazing livestock.

Introduction Grazing is arguably the cheapest source of ruminant livestock feed, and it is perceived by consumers as being natural and welfare friendly. However, good grazing management can be a challenge for all but the most experienced farmers, and, for many, the inability to measure grazing makes it too much of an 'act of faith'. The field of Precision Livestock Farming (PLF) has already had a big impact in intensive dairy production, and the approach has the potential to bring to tools to grazing management that will improve production efficiency as well as animal health and welfare.

Measuring performance Electronic identification (or EID) is the core technology in PLF as it allows individuals animals to be identified, facilitating individual monitoring and management. EID can be combined with a strategically placed electronic weigh platform to record the liveweight of stock in a 'walk over weigher' (WOW), allowing growth to be monitored as well as detecting the weight loss associated with disease or injury. Although Brown *et al.* (2014) were unable to get sufficiently reliable WOW data to be able to recommend the approach to farmers, improvements in the reliability of EID and automated weight measurement should make WOW a useful tool in the future.

Estimating grazing and intake Neck mounted accelerometers can be used to estimate grazing time (Oudshoorn *et al.* 2013), and commercial systems that use this approach are already available e.g. Needap Smarttag Neck. Although grazing time is a useful measure, it is not a good predictor of herbage intake as grazing animals spend a variable proportion of their foraging time searching for specific plant components and, in mixed swards, plant species (Rutter 2006). The sounds associated with grazing can be used to distinguish between bites and chews (Ungar and Rutter, 2006), and the energy flux density of the sound of chewing is proportional to bite mass (Laca and WallisDeVries, 2000). Thus bioacoustics can be used to measure both grazing time and intake, although further development is needed to develop a practical, on-farm system using this approach. As well as providing individual animal herbage intake data, the ratio of bites:chews changes with sward depletion, so could be used to help determine when grazing stock need to be moved to fresh pasture.

Controlling pasture access Timed and remote release gates are already commercially available (e.g. Batt-Latch), and these could in the future be linked with grazing behaviour measurements to automatically give stock access to fresh pasture at the optimum level of sward depletion. Virtual fencing involves livestock wearing collars that determine the animal's location (e.g. with GPS) in relation to a 'virtual' boundary, and the animal learns, using auditory cues, to avoid crossing the boundary otherwise it receives an electric shock (Umstatter, 2011). The first commercial virtual fence system is expected to come to market later in 2017. Ethical concerns may limit the use of virtual fences in some countries, and more research is needed into the potential of guiding stock using positive reinforcement. By making the virtual boundaries dynamic, grazing livestock can be moved to fresh feed (based on remote monitoring via e.g. satellite) or to shelter depending on the weather forecast. Such a 'virtual shepherd' system mimics the monitoring and control associated with traditional shepherding.

Monitoring health and welfare The frequent monitoring of foraging behaviour, daily movement and livewight will enable changes in these parameters associated with disease or injury to be rapidly detected, and the affected animal(s) could be guided by the 'virtual shepherd' to a pen for inspection and treatment, improving health and welfare (Rutter, 2014).

Conclusion Although not intended to replace the skills of the farmer, PLF approaches to grazing management have the potential to improve production efficiency whilst also improving animal health and welfare in extensive grazing systems.

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Profitability of controlled traffic in grass silage production – economic modelling and machinery systems

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Controlled traffic farming (CTF) systems aim to reduce soil compaction by restricting machinery field traffic to permanent traffic lanes. Grass-clover silage production is generally associated with intensive field traffic, resulting in reduced silage clover content. If CTF can increase yield and clover content in grass-clover leys, this would reduce the need for grain and expensive protein concentrate in dairy cow feed rations. A mixed integer programming model was developed to evaluate the potential profitability of CTF in a dairy farm context. Existing field trial data were used to calculate the expected yield outcome of CTF, based on reductions in trafficked area. The results revealed that CTF increased profitability by up to €50/ha. Total machinery costs are likely to increase on converting to CTF, but variable machinery costs are likely to decrease.

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Potential for controlled traffic farming (CTF) in Grass Silage Production: Agronomics, system design and economics

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Grassland silage management is generally ad hoc resulting in soil compaction damage. Literature suggests grass yield reductions of 5 to 74% through compaction (UK mean 13%), while a 2015 study, reported here, comparing grass dry matter (DM) yield between controlled traffic farming (CTF) and normal management (N), found a 13.5% (0.80 t ha−1) increase for CTF. Commercially available grass forage equipment with widths of 3 to 12 m set up for CTF reduced trafficked areas from 80%–90% for N to 40%–13%. Economic analysis based on 13% increase in DM for 2 and 3 cut systems, gave an increased grass value between £38 ha−1 and £98 ha−1. CTF for multi-cut grass silage effectively increases yields by reducing compaction and sward damage.

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A review of precision agriculture as an aid to nutrient management in intensive grassland areas in North West Europe

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Great technological advances have been made in Precision Agriculture (PA) in the past decade, yet adoption of PA in intensive grassland areas in North West Europe is low. This is despite the fact that in these areas the market structures are suitable and there are highly developed agricultural and food industries offering great potential for the application of new technology. Specific inefficiencies in plant nutrient management in soil exist, which are not only limiting grass yields but are also causing environmental deterioration. Soil nutrient management efficiency could be greatly improved using PA techniques, but the complexity of grassland systems, coupled with a lack of calibration of sensors specific to grassland, together with local barriers, appear to be the reasons why PA adoption is poor in these areas. This paper reviews new and existing technology including soil and crop sensors, navigation devices, remote sensing and unmanned aerial vehicles. The suitability and readiness of these technologies for adoption in grassland areas is discussed, along with data interpretation issues, future perspectives and research opportunities.

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Estimating pasture biomass with active optical sensors

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We investigated relationship between pasture biomass and measures of height and NDVI (normalised difference vegetation index). The pastures were tall fescue (Festuca arundinacea), perennial ryegrass (Lolium perenne), and phalaris (Phalaris aquatica) located in Tasmania, Victoria and in the Northern Tablelands of NSW, Australia. Using the Trimble® GreenSeeker® Handheld active optical sensor (AOS) to measure NDVI, and a rising plate meter, the optimal model to estimate green dry biomass (GDM) during two years was a combination of NDVI and falling plate height index. The combined index was significantly correlated with GDM in each region during winter and spring ($r2 = 0.62–0.77$, $P < 0.001$). Regional calibrations provided a smaller error in estimates of green biomass, required for potential application in the field, compared to a single overall calibration. Data collected in a third year will be used to test the accuracy of the models.

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Development of methods for remotely sensing grass growth to enable precision application of nitrogen fertilizer

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A 'chessboard' field experiment set up to investigate how the yield response to nitrogen (N) fertiliser varied spatially within a field in the UK indicated that the optimum N rate varied substantially by up to 100 kg N/ha within the three hectare experimental area. Variation in N optima was negatively related to the soil N supply. However, soil N supply, yield potential and apparent fertiliser recovery rate were inter-related which meant that the influence of each element on N optima was complex. Spectral reflectance indices related well to crop N uptake and could be used to help estimate soil N supply.

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Hyperspectral aerial imaging for grassland yield estimation

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In this study, we investigated the potential of airborne imaging spectroscopy for in-season grassland yield estimation. We utilized an unmanned aerial vehicle and a hyperspectral imager to measure radiation, ranging from 455 to 780 nm. Initially, we assessed the spectral signature of five typical grassland species by principal component analysis, and identified a distinct reflectance difference, especially between the erectophil grasses and the planophil clover leaves. Then, we analyzed the reflectance of a typical Norwegian sward composition at different harvest dates. In order to estimate yields (dry matter, DM), several powered partial least squares (PPLS) regression and linear regression (LR) models were fitted to the reflectance data and prediction performance of these models were compared with that of simple LR models, based on selected vegetation indices and plant height. We achieved the highest prediction accuracies by means of PPLS, with relative errors of prediction from 9.1 to 11.8% (329 to 487 kg DM ha−1) for the individual harvest dates and 14.3% (558 kg DM ha−1) for a generalized model.

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Interactions between landscape defined management zones and grazing management systems

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Yield and landscape are commonly used to guide management zone delineation. However, production system choice and management can interact with landscape attributes and weather. The objective of this study was to evaluate forage yield and soil properties in three landscape defined (elevation based) management zones, and under two different grazing systems. Changes in soil properties (soil strength, bulk density, moisture, bioavailable nutrients) and forage productivity (biomass), as related to grazing management and management zone, were measured. Bulk density, moisture, and forage biomass were greater at higher elevation. Soil strength decreased as elevation increased, and was greater near-surface after winter grazing ended. The response of landscape delineated management zones varied with extreme weather conditions and treatment. Lower zones were more sensitive to weather extremes than higher elevations, directly affecting biomass accumulation. In conclusion, we observed interactions between the grazing treatments and the management zones.

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Capability of crop canopy sensing to predict crop parameters of cut grass swards aiming at early season variable rate nitrogen top dressings

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This study aims to evaluate actual biomass and N-uptake estimates with the Yara N-Sensor in intensively managed grass swards across several trial sites in Europe. The dataset was split by location into an independent calibration data (UK and Finland) and a validation data (Germany) for the first two cuts. Yara N-Sensor readings were better correlated with N-uptake (R2 = 0.71) than actual biomass (R2 = 0.53) for the 1st cut. At the 2nd cut, the R2 values for both parameters were higher (0.80 and 0.56). A cross-validation with a German grass trial indicated the potential for predicting N-uptake (R2 > 0.8). It can be concluded that the technology has the potential to guide management decisions and variable rate nitrogen application on European grass swards.

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Proximal sensing for monitoring the productivity of a permanent Mediterranean pasture: influence of rainfall patterns

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The main objective of this work was to evaluate technologies that have potential for monitoring aspects related to spatial and temporal variability of soil nutrients and pasture yield and for support to decision making by the farmers. Three types of sensors were evaluated: an electromagnetic induction sensor, an active optical sensor and a capacitance probe. The results are relevant for the selection of the adequate sensing system for each particular application and to open new perspectives for other works that would allow the testing, calibration and validation of the sensors in a wider range of pasture production conditions and rainfall patterns, characteristic of the Mediterranean region.

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Soil electrical resistivity at different water contents in an integrated crop-livestock-forest system in Brazil

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Application Characterizing the spatial variability of soil properties can be very useful in decision-making for crop management strategies. The electrical resistivity (ER) of the soil is a function of the soil texture and structure and sensitive to soil water content.

Introduction Soil properties may vary spatially within a plot or at a regional scale, due to intrinsic factors (clay content, water retention capacity, stoniness, source material) and extrinsic factors (structure, temperature, water content, management practices, fertilization and crop rotation). These variations in soil properties should be monitored to understand the effects of land use and land management systems. From the agricultural point of view, the main physical indicators of soil quality are texture, structure, resistance to penetration, rooting and water storage. The electrical resistivity (ER) of the soil (Ω m) is a measure of its resistance to an electric current. ER is a function of the soil texture and structure, particularly sensitive to water content. In most of the field studies, ER was used to monitor water dynamics in the soil under controlled conditions. Few studies have been conducted to monitor changes in ER as a function of soil moisture at a field scale. Therefore, water content in the soil should be considered in studies of electrical resistivity. The aim of this study was to characterize the spatial variability of soil ER in different soil moistures in integrated systems.

Material and methods This research was conducted in a study area of 9.7 ha of the crop-livestock-forest integration system (CLFIS) at Embrapa Pecuária Sudeste in São Carlos, Brazil (21 ° 57'S, 47 ° 50'W, 860 m alt) in a Red-yellow Latosol, i.e. Haplortox. The climate is tropical of altitude, with 1502 mm of annual rainfall and average minimum temperature and maximum temperature of 16.3 ° C (July) and 23 ° C (February), respectively. The CLFIS system includes different combinations of Piatã grass (*Urochloa brizantha),* corn (*Zea mays*) and *Eucalyptus urograndis* (GG100). ER measurements were obtained with the commercial sensor ARP system® (Geocarta, Paris, France) on two dates (May 4th, 2016 and Jun 1st, 2016). Soil moisture content was monitored with a Diviner 2000 probe (Sentek Environmental Technologies, Kent Town, Australia). Weather data were collected, and water balance was calculated and shown in Figure 1. The inverse distance weighting (IDW) method was used for data interpolation and generated contour maps using ArcGIS 10.1 software. From the maps obtained by IDW, values were sampled at the same geographical position in a virtual sampling grid of 500 points, regularly distributed over the set of data predicted for the study area and a correlation study was carried out.

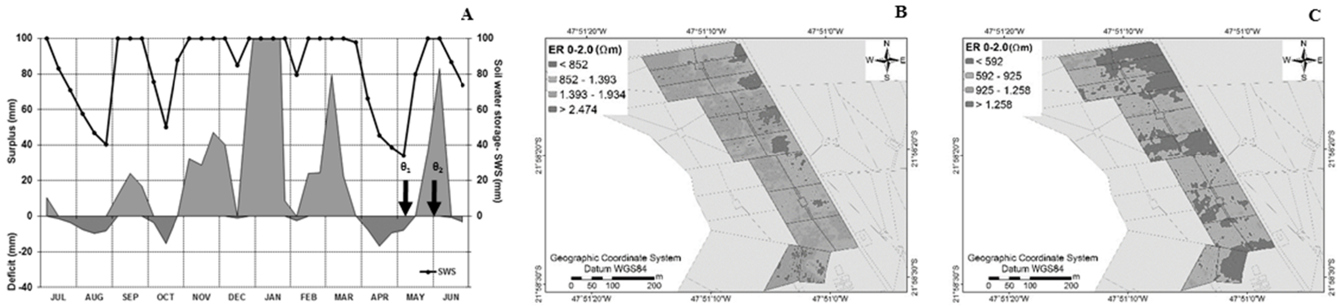

Figure 1 Soil water balance (A) and interpolated maps of soil electrical resistivity at 0-2.0 m depths with soil water at 0.208 $cm^3 cm^{-3}$ (θ_1 - B) and 0.283 $cm^3 cm^{-3}$ (θ_2 - C).

Results Between measurements a 216-mm rainfall event was recorded, leading to accumulation of water in the soil (Figure 1). At both dates, the recorded soil moisture (θ) contents (up to 1 m deep) were, respectively, 0.208 and 0.283 $cm^3 cm^{-3}$. After interpolation of the ER data for all three depths, four classes of division were established. Measurements at the 0-50 cm and 0-100 cm layers indicated little variation in soil water contents. The largest differences were observed in the measurements at the depth of 0-200 cm (Figure 1B and C), which were initially mainly in classes 2 and 3 (representing 48 and 43% of the area), and with the accumulation of water after the rain, the measured values changed predominantly to classes 1 and 2 (36 and 62 area%, respectively). This is probably due to high rates of water infiltration by the Red-yellow Latosol. The coefficient of correlation between interpolated maps of soil electrical resistivity at 0-2.0 m depths with soil water (θ) at 0.208 $cm^3 cm^{-3}$ (May 4th) and 0.283 $cm^3 cm^{-3}$ (June 1st) was $r = 0.65$ ($p<0.05$).

Discussion The results indicated that with ER, it was possible to establish the relationship between electrical resistivity and soil moisture content. Therefore, this spatial variability represents the variability of soil properties which can change the ER, such as porosity, structure, temperature and chemical composition of the solution. The results confirm the potential use of electrical resistivity measurements (ER) as an auxiliary tool for soil science and agronomy.

Conclusion ER allowed the delimitation of regions within the studied area, indicating differences of movement and accumulation of water in the soil horizons. There was a trend of reduction in ER values with increasing soil moisture.

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To Geocarta, for the mapping of the area.

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MitAgator – a GIS based spatial tool to manage nitrogen, phosphorus, sediment and E.*coli* losses from pasture

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Application Water quality management tools usually focus on losses of nitrogen (N) and phosphorus (P), missing the other important factors of sediment and E.c*oli*. MitAgator is a spatial modelling tool that helps manage all four key losses from pasture.

Introduction Increasing pressure to balance the twin objectives of improving productivity whilst maintaining/improving environmental outcomes has meant there is a need for better management tools to help guide farmers in making decisions on farm to achieve this. Many of the available tools currently fall short by only focussing on nutrients or are hard to use or understand. In order to overcome this, Ballance AgriNutrients (NZ's largest fertiliser company) has developed a spatial modelling tool that provides improvements over current tools by taking into account a wider range of important factors (sediment and faecal losses), identifies critical source areas where more targeted mitigations can yield better results and displays the information in both textual and spatial outputs. The combination of these factors results in greater farmer uptake and better environmental outcomes through lower contaminant losses.

Material and methods A large research project by the New Zealand Government called 'Clean Water, Productive Land" which concluded in 2010, yielded a lot of new information around factors affecting water quality, including the key sources of contaminant and the impact of various mitigation strategies designed to help reduce those losses. Ballance in conjunction with its government partner (Ministry for Primary Industries) launched a project to combine the learnings of the research with the latest advances in GIS technology to create a modelling tool that could not only more accurately estimate losses from pastoral farms but also provide recommendations on the most effective mitigation strategies along with their costs. The tool uses outputs from the Overseer nutrient budgeting tool and combines them with a geo referenced farm map, digital soil and elevation maps and aerial map. Importantly the spatial capability allows CSAs to be identified and appropriate mitigation strategies targeted to those areas. The recommendations and output options are displayed in both spatial and textual form.

Results The model firstly produces results which identify all of the critical source areas and quantifies the loss from those areas as well as at a block and farm scale. This information is then used to produce risk maps highlighting the key areas to target for mitigations. The model then gives the user the option of choosing a target percentage reduction or budget spend ($/ha) to generate a range of mitigation options (chosen from 27 available) to achieve those targets. Alternatively the user can apply a specific mitigation to a designated area and test out its effectiveness. Once a mitigation(s) has been selected the model will then produce a report showing the losses of nutrients, sediments and faecal coliforms both before and after the mitigations at a block and farm scale as well as the cost ($/ha) and cost effectiveness ($/kg nutrient saved) of the mitigation(s). Comprehensive user testing has shown that the flexibility and range of displays (both textual and spatial) allows for much better understanding of the issues and solutions by farmers and as such results in a much greater likelihood of achieving a positive outcome and solution.

Conclusion The MitAgator tool draws on the most up to date science around contaminant loss from pastures as well as the mitigation options available to manage these losses and combines them with geospatial technology to deliver a superior decision support tool for managing and reducing environmental harm. The combination of using the most advanced scientific information around nutrient and contaminant management along with displaying the information in a farmer friendly format allows for greater understanding and better application and uptake of mitigation solutions.

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Pastures from Space® Plus for teaching precision pasture management

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Application Agri-tech learning modules taught in high schools will inform students of the latest innovations in agriculture and inspire them to consider further education and/or a career in the field, securing workforce capacity.

Introduction The SmartFarm Learning Hub (the Hub) is a collaborative project between seven universities, aiming to increase the knowledge and skill base of students studying agricultural technology at a tertiary level. A case study in this project involves developing a 'Real Industry Technology Learning System' (RITLS) module for high school students, aligned to the Year 9 & 10 Agricultural Science curriculum in New South Wales (NSW), Australia. Educational activities focussed on agricultural technologies have been demonstrated to engage students and consistently rate highly in student assessments and feedback (Cosby & Trotter, 2014). As there is currently a skills shortage in the Australian agriculture industry, with an estimated four jobs available for every tertiary agricultural graduate (Pratley & Botwright Acuna, 2015), it is hoped the use of RITLS modules in high schools will inspire the next generation to consider tertiary study and a career in the sector.

Material and methods Seventeen high school teachers, curriculum consultants and a school Principal were invited to attend a workshop where they were guided through a series of RITLS modules. One of these modules was the Pastures from Space® Plus (PFS+) RITLS. Participants learnt about PFS+ and how the program uses normalised difference vegetation index (NDVI) derived from satellite imagery, climatic information and plant growth models to calculate pasture growth rate and food on offer for individual farms (Western Australian Land Information Authority, n.d.) At the conclusion of each RITLS module, workshop attendees completed an online survey asking a range of questions on a variety of aspects of the practical.

Results The aim of this workshop was to determine the suitability of three RITLS modules for integration into their teaching. Reported are the results of two questions. Fifty-three percent of respondents indicated they strongly agreed or agreed that the completion of the PFS module will encourage students to commence study at a tertiary level in agriculture. Seventy-six percent of participants strongly agreed or agreed that student knowledge of contemporary issues would improve as a result of completing the practical. Comments received from classroom teachers indicate that the instructions of the practical needed to be simplified for high school students. To increase the strength of the PFS+ to encourage students to consider tertiary study in agriculture, a greater focus will be placed on the application of the program to solving real world problems in the revised RITLS module. A new feature of PFS+, the stocking rate calculator, will also be included in the revised practical to demonstrate to students the interaction between grazing livestock and pasture production.

ConclusionThe PFS+ RITLS has the potential to increase high school students' knowledge of contemporary issues in agriculture to inspire them to consider tertiary study in agriculture. Amendments need to be made to the practical to ensure directions are simplified and clearer are required. Case studies of famers using PFS+ and problem based questions asking students to solve real on-farm issues using PFS will be included encouraging students to develop critical thinking skills when analysing agricultural problems.

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Cultivar selection by cattle grazing tall fescue infected with novel endophytes

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Application In a low pressure grazing system, BarOptima tall fescue was grazed more frequently than other tall fescue cultivars, whether they were endophyte-free or infected with a novel or toxic endophyte.

Introduction Common tall fescue is infected with a fungal endophyte (E+) that causes the devastating livestock disorder, fescue toxicosis (Bacon *et al*., 1977). Toxicosis has been eliminated in previous decades by planting endophyte-free (E-) cultivars. However, E- cultivars do not persist in stress environments. Most recently, tall fescue has been re-infected with fungal strains called “novel endophytes” (E++), which are nontoxic strains of the fungus (Bouton *et al*., 2002). This study was conducted to determine if cattle would preferentially select E++ cultivars in a low pressure grazing system.

Material and methods Eight cultivars of tall fescue were planted in 9 x 12 m plots in Linneus, MO, USA and grazed by non-lactating beef cattle fitted with Loteck GPS collars (Newmarket, Ontario, Canada). Plots were grazed between March and November five times in 2013 and four times in 2014. Grazing events began when forage reached 2500 to 3000 kg/ha and concluded when one plot reached 8 cm in height. Grazing events ranged from 10 to 22 h and averaged 15 h. Latitude and longitude were recorded every 5 min to indicate cattle location within plots. Altitude and angle of head were also recorded every 5 min to calculate head up/down and indicate active grazing. Cattle were considered loafing when sensors indicated that the head was up and the distance between consecutive points was less than 1 m. After each event, plots were clipped and the clippings removed. Forage samples were collected from each plot and analysed for crude protein, acid detergent fibre (ADF), neutral detergent fibre (NDF). Experimental data were statistically analysed by PROC GLIMMIX (SAS Institute, Cary, NC, USA) as a randomized complete block design with eight cultivars, four blocks, nine grazing events, and two years. Cultivar was considered fixed, and other effects were considered random.

Results The cultivar BarOptima received the most GPS hits with head down ($P<0.01$), indicating it was actively grazed more often than other cultivars (Table 1). Cultivars did not differ in crude protein, ADF or NDF ($P>0.05$), which was expected as forage was maintained in a vegetative state. However, cultivars did differ in leaf texture; BarOptima was the only cultivar with the soft leaf trait.

Table 1 Active grazing GPS data for cattle grazing tall cultivars infected with novel endophytes and E+ and E- controls.

Cultivar	Active Grazing GPS Hits per Plot ‡	
BarOptima	17.7	a†
Martin 2	10.6	b
Texoma	10.3	b
E+ KY31	10.1	b
E- KY31	9.3	b
Estancia	8.9	b
Duramax	8.7	b
Jesup	8.6	b
LSD (0.05)	2.4	b

‡ Excluding border and watering areas, averaged over 2 collared cows and 9 grazing events with 10 to 22 h per event
† Means followed by the same letter are not significantly different according to LSD (0.05).

Conclusion We concluded that BarOptima was grazed more frequently than other cultivars likely because of its leaf texture. BarOptima was the only cultivar in the trial with the soft leaf trait. These findings apply to grazing systems that employ livestock rotations, adequate pasture rest periods, and grazing restrictions to 8 cm and above in the canopy.

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Low-cost GPS collars: An alternative to commercial collars for tracking cattle during rangeland research

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Application Collars housing i-gotU global positioning system (GPS) receivers can be constructed for 10 to 20% of the cost of commercial collars. Accuracy of recorded positions is similar to Lotek GPS 3300 collars, but the i-gotU collars miss from 26 to 34% of the positions scheduled to be recorded. The i-gotU receiver is a low-cost alternative to track cattle for many, but not all, rangeland research scenarios.

Introduction The use of GPS receivers is integral component of precision livestock management research, and they have been used extensively in grazing behaviour and rangeland management studies. Typically, researchers have limited the number of cattle tracked in research because of collar cost. Consequently, researchers have developed their own GPS tracking collars, but many have problems because of the rugged construction needed for rangeland cattle. Allan et al. (2013) developed a low-cost GPS collar for tracking wildlife based on the Mobile Action i-gotU GT-120. A rugged collar housing for i-gotU GPS receivers to increase our ability to track a large number of cattle in rangeland pastures was developed. The objective of this study was to evaluate the efficacy of using i-gotU GT-120 GPS collars compared with the commonly-used and commercially-available Lotek GPS 3300 tracking collars.

Material and methods To enable the i-gotU GT 120 GPS receiver to track for long periods, a 5200 mAh rechargeable lithium ion battery was attached to the receiver. Units were placed in waterproof plastic bags and then placed in a leather pouch attached to a leather belt to form a collar (Knight collar). Cost of the Knight collar was $180 USD. Eight mature Brangus cows were fitted with both a Knight collar and Lotek GPS 3300 collar and tracked for 31 days at the Chihuahuan Desert Rangeland Research Center (CDRRC), located 35 km north of Las Cruces, New Mexico, USA. Positions were scheduled to be recorded at 10 minute intervals. The 922 ha paddock used at the CDRRC included gentle terrain and few areas with moderate slopes. Average slope and elevations use as well as distance from water and distance travelled per day were calculated for each collar type on each cow and compared using t-tests. To validate results from the CDRRC, 6 Angus cows fitted with Knight collars and 11 Angus cows fitted with Lotek GPS 3300 collars were tracked for 5 months at 10 minute intervals on mountainous terrain in central Nevada, near Austin, NV, USA (University of Nevada, Gund Ranch).

Results At the CDRRC, Knight collars recorded 66% of the scheduled positions, which was less ($P < 0.001$) than the 99% recorded by the Lotek collars. No differences were detected ($P > 0.05$) between Knight and Lotek collars for cattle use of slopes, higher elevations, and distance from water. Distance travelled per day tended to be less ($P = 0.08$) for the Knight collars than the Lotek collars, likely because of the lower fix rate for the Knight collars (Ganskopp and Johnson, 2007). Similarly, the Knight collars missed 26% of scheduled positions at the mountainous Gund Ranch, while the Lotek collar missed 7%. The number of inaccurate positions recorded by both the Knight and Lotek collars at the Gund Ranch was less than 1%.

Conclusion The accuracy of the less expensive Knight collars using the i-gotU GPS receiver were similar to commercially available Lotek GPS 3300 collars. However, the i-gotU GPS receiver missed between 26 to 34% of the scheduled positions, and the Lotek collars missed 7% or less of scheduled positions. The antenna on the Lotek collar is on top of the neck, but the i-gotU GPS receiver and antenna are integrated on the same unit and were located below or on the side of the neck to make the collar more rugged and durable. The position of the i-gotU receiver likely limited its ability to record positions because of interference from the cow's neck and head. Another benefit of Lotek units are accelerometers and temperature sensors that are built into the collar. Knight collars only have GPS receivers. The Knight collar using the i-gotU GT 120 GPS unit are relatively inexpensive to construct ($180 USD), while Lotek GPS 3300 collars are over $1800 USD. Accelerometer ear tags could be constructed for under $150 USD if researchers needed motion sensors and used Knight collars for GPS tracking. The i-gotU GT 120 GPS receiver integrated into the Knight collar or similarly designed collars allow researchers with limited funding to track more cattle at one time. Knight collars accurately recorded spatial movement patterns of cows in mountainous terrain for over 5 months and allowed researcher to readily differentiate between spatial movement patterns of individual tracked cows. If experimental designs can allow for missing positions during tracking, less expensive collars may be a cost-effective option for extensive and rugged rangeland conditions.

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The application of a weight-based targeted selective wormer treatment (TST) strategy on hill and upland sheep flocks

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Application Wormer resistance is a problem in livestock grazing systems worldwide. The rate of development of wormer resistance can be slowed by leaving some worms unexposed to drugs, by targeted dosing using precision farming methods. This approach was tested on hill/upland sheep flocks.

Introduction Roundworm infection is a major cause of lost productivity in livestock farming systems. Refugia based worming strategies, where a proportion of the animals (therefore worms) are left unexposed to drugs to maintain genes for susceptibility in the worm populations can optimise wormer use, slow the development of anthelmintic (wormer) resistance providing sustainable nematode control. Wormer can be targeted to individual animals within a flock using short-term weight gain as an indicator for treatment (targeted selective worming treatment (TST)). The Happy Factor decision support system, using grass availability and lamb growth rates, and where individual lambs receive wormer only if they fail to reach pre-determined weight gain targets using a production efficiency threshold of 0.66, has been shown to reduce the number of wormer treatments with no negative effects on lamb growth in a number of lowland sheep farms (Greer et al 2009; Kenyon et al 2013). However, this system has not yet been tested on upland or hill farms.

Material and methods A study (2012 – 2015) was conducted on a mountain research farm in the western Highlands of Scotland, at SRUC's Hill and Mountain Research Centre, to compare different approaches to ewe management, nutrition and lamb worming. The flock (mean n=902 ewes) was allocated to two systems, balanced for age, genotype, live weight, litter size and sire; a conventionally managed (CON mean n=435 ewes/year) and a precision livestock farming (PLF) approach (mean n = 467 ewes/year). Ewes and lambs ran together irrespective of main treatment, between the hill ground and a series of fields during summer months. This paper focuses solely on results generated by the use of the TST approach for lamb worming. All lambs were individually tagged with electronic ear tags and weighed each month, from approx. 8 weeks of age, at marking (June), shearing (July), weaning (August) and post-weaning (September). Worming decisions were made monthly from July to September, PLF lambs were wormed (following manufacturers recommended dosage rate to the nearest 10 kg) only if they did not meet individual weight gain targets, calculated using the Happy Factor. CON lambs were wormed if a pooled faecal egg count across all groups of lambs reared in the same litter size (singles and twins assessed separately) was > 500 eggs/g, and received a full dose based on the heaviest animal. Labour (hours) was measured using videos and direct observations and labour costs (£11/hour) calculated. Worming costs were calculated based on the total amount of wormer used in each system, and FEC costs. Data were analysed with parametric and non-parametric tests. Lamb performance differences between the two management systems were investigated by means of Linear Mixed Models (LMM), with 'year' as a random effect. For the lamb performance at weaning and post-weaning, the lamb breed, lamb sex, lamb age, lamb birth weight and system were fitted in the LMM. The percentage of lambs dosed in each system was compared using non-parametric tests (χ^2 test).

Results Overall there was no statistically significant difference between the two systems for lamb weight post-weaning. However, the total number of lambs that required worming was lower (χ^2 test, $P<0.001$) in the PLF (1495) than in the CON (2428) groups, across all possible worming events and years. On average, lambs in CON were dosed 2.12 ±0.60 times compared to 1.23 ±0.64 times in PLF. This reduction in the number of lambs wormed also resulted in reduction of labour required (217 hours in PLF vs 316 hours in CON over the 3 years), reducing labour and worm treatment costs by approx. £1.60 per lamb in the PLF group, an important consideration when seeking to encourage uptake among farmers.

Conclusion This study showed that a precision livestock approach, working at the individual animal level, can be implemented on hill/mountain flocks. The implementation of the TST worming approach resulted in a sustainable worming approach by reducing wormer usage and labour required with no negative effects on final lamb weights.

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Evaluating precision management of sheep in a hill farming system

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Application Using EID technology for sheep management on hill farms, based upon recording animal live weights at certain points throughout the year, can improve profitability and resilience.

Introduction: Electronic Identification (EID) in sheep flocks was made compulsory in the UK in 2010, to improve individual animal identification. Whilst all farmers EID-tag their animals, the potential benefits from using EID technology to improve animal performance are scarcely exploited by sheep farmers in more extensive hill farming systems. Sheep farmers tend to manage their flock at a group ('batch') level rather than an individual level, but the introduction of EID makes it possible to change this practice. This paper presents results from research that has been carried out exploring the possibilities of applying EID technology for best practice in extensive sheep management.

Materials and methods The research was based at the SRUC's Hill & Mountain Research Centre in the West Highlands of Scotland. The farm carries a total of 1300 hill ewes and 22 hill cattle, on 2200 ha. Most of the land is rough grazing, with only 230 ha of improved and semi-improved pastures. In this systems study (2012-2015), 900 hill ewes were allocated to two management systems balanced for genotype, age, live weight, litter size in the first project year and sire. The first system was managed conventionally (control - CON), the other with a Precision Livestock Farming (PLF) management protocol, based around the use of EID technology. Two management decisions were considered in this study: the winter feeding of the pregnant ewes and the anthelmintic treatment of lambs throughout the summer.

During the winter feeding part of the study, ewes in the CON system were allocated to their respective feeding groups, receiving more or less feed per head, based on body condition, assessed by hand by the stockperson. Ewes in the PLF system were assigned to feeding groups based on individual animal live weight changes, by using the EID auto-weighing and -sorting technology.

For the anthelmintic treatment of lambs, animals in the CON system were wormed based on pooled faecal egg counts (FEC) for the group, whilst in the PLF system, the lambs were treated using a Targeted Selective Treatment approach (McBean et al., 2016), based on their individual weight change (details of the latter are presented in another abstract by Kenyon et al. in this conference).

Ewe live weights (at mid-pregnancy scanning, pre-lambing and weaning) and lamb live weights (at birth, marking, shearing, weaning, post-weaning) were recorded during the study period. On-farm labour was quantified at each of the major handling events using videos and direct observations, and financial data for the two systems were also collected to estimate net margins. Parametric (Linear Mixed Models with 'year' as a random effect) and non-parametric tests (χ^2) in the GenStat statistical package were used to analyse the results.

Results Results showed that, overall, the winter feeding management system did not have a significant ($P<0.05$) effect on ewe weight at scanning (CON=47.9 ±8.2 kg; PLF=48.5 ±8.7 kg), pre-lambing (CON=51.9 ±7.4 kg; PLF=52.5 ±8.0 kg) or weaning (CON=53.8 ±6.8 kg; PLF=53.9 ±7.2 kg). Lamb final weights (post-weaning weights) were also not affected by system (CON=30.7 ±5.2 kg; PLF= 30.4 ±5.1; $P<0.05$), but the proportion of lambs needing treatment was reduced by 40% ($P<0.001$), with the CON lambs needing a yearly average of 10.9 litres of anthelmintic compared to only 5.9 litres for the PLF lambs. Across all years, a total number of 2428 CON lambs were treated, compared to 1495 PLF lambs.

The PLF system showed average annual labour savings of around 40% (CON=42 days; PLF=25 days, based on an 8 hour day). Specifically, the average annual labour savings at winter feeding were 17% (CON=4 days; PLF=3 days), whilst the average annual labour savings for the targeted worming were 32% (CON=13 days; PLF=9 days). Overall, the financial savings showed a difference in net margin at farm level of £4/ewe, to the benefit of the PLF system.

Conclusions: It is feasible and financially rewarding to use EID technology for best practice management on a hill sheep farming system. The next steps of this systems study (2016-2017) are to extend the PLF management protocol to the whole flock and to fully include complementary grassland management.

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Evaluation of the RumiWatch technology for measuring detailed grazing activities of cows

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Application This study indicates that the RumiWatch technology is reliable for observing and recording detailed grazing activities in a pasture based system and may be used for research and management purposes in a grazing environment.

Introduction It is of key importance to measure, manage and allocate grass accurately to cows in a pasture based system in order to optimise farm efficiency and profitability. The RumiWatch technology is well established as a sensor technology in indoor housing systems (Zehner et al., 2017) and it has undergone a number of modifications to allow it to operate in a pasture grazing situation. While measurement of animal behaviour parameters such as grazing, rumination, walking, standing and lying time have been validated with an updated version of the RumiWatch (in publication process), the objective of this study was to validate it for the measurement of the detailed parameters of grazing bites and rumination chews.

Material and methods A group of twelve spring calving dairy cows were fitted with RumiWatch noseband sensors. The experiment extended over a 2-day-period with a pre-experimental adjustment period of 8 days. The cows were on a grass only diet with fresh grass provided on a daily basis. With the visual observation, the accordance between four observers was ensured prior to the experiment. The number of grazing bites and rumination chews was recorded (in 5-min periods) using a handheld computer with a programmed application. In total 249 observation periods were recorded over the 2-day period. A grazing bite was defined as a combination of jaw, tongue and neck movement to rip grass with an under-laid acoustic sound. Rumination chews were counted as regurgitation after a bolus travelled through the oesophagus to the mouth. The data recorded by the RumiWatch were converted into 5-min intervals, summarizing the numbers of rumination chews or grazing bites. Number of grazing bites and rumination chews per 5-min period were analysed using methods for numeric variables including Spearman's Rank correlation, a concordance correlation coefficient (CCC) and Bland-Altman-Analysis.

Results The comparison between the automated system and visual observations in measuring grazing bites and rumination chews are presented in Table 1. The visually counted grazing bites ranged from 0 to 387 per 5-min period, with a median of 232 bites. The RumiWatch recorded grazing bites between 0 and 419, with a median of 280 bites. Overall, the agreement for grazing bites between the two measurement methods was high, with $r_s = 0.81$ and a CCC = 0.78. The visually counted rumination chews ranged from 2 to 386 chews/5-min period with a median of 323 chews. Alternatively, the RumiWatch recorded a median of 330 rumination chews. The agreement between observer and automated system was higher compared to that for grazing bites, with a correlation of r = 0.81 and a CCC = 0.94.

Table 1 Spearman's rho (r_s), Concordance Correlation Coefficient (CCC), and Bland-Altman-analysis (Bias, upper and lower 95% limits of agreement with 95% CI) of RumiWatch and visual observations of grazing bites and rumination chews

Behaviour (n./5min)	r_s	CCC	Bias (95% CI)	Lower (95% CI)	Upper (95% CI)
Grazing bites	0.81	0.78	36.01 (28.36; 43.66)	-66.16 (-79.41; -52.93)	138.19 (124.95; 151.44)
Rumination chews	0.81	0.94	7.24 (-0.15; -14.33)	-51.44 (-63.72; -39.17)	65.92 (53.64; 78.19)

Conclusion With the wide ability of recording every jaw movement and the specific differentiation in grazing bites and rumination chews, the RumiWatch technology is an applicable tool for measuring grazing behaviour long-term. With further development, it may be suitable to estimate feed intake of dairy cows on pasture, based on measuring bites and chews. Therefore, the availability of this accurate and reliable automated technology may be very useful and appropriate.

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Effect of climatic conditions on nocturnal behavior of dairy cows grazing on Alpine pasture

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Application An automatic noseband sensor has proved a valuable tool for the assessment of the nocturnal behavior of grazing cows on pasture. In this study the grazing behavior was not affected by climatic conditions.

Introduction Dairy cattle are often kept day and night on Alpine pastures during summer grazing. The knowledge of the animals' behaviour can help the farmer to optimize the pasture management. The assessment of the nocturnal behaviour of dairy cattle with traditional methods is difficult and only recently appropriate electronic instruments for the continuous monitoring of feeding behaviour were developed. During the warmest hours of the day, the weather conditions can affect the behavior of dairy cows on pasture (Tucker et al., 2008). The aim of the study is to verify whether these changes may have an impact also on nocturnal behavior of the cows.

Material and methods A herd of 110 lactating cows of a local dual purpose breed were maintained day and night on an Alpine pasture. Cows were milked twice a day and, during milking, received 2.5 kg/head/day of concentrate. Sixteen dairy cows were selected from the herd and monitored, along the experimental period, for feeding and locomotion behaviour. An automatic noseband sensor (RumiWatch, ITIN-HOCH, Switzerland), validated by Ruuska et al. (2016), assessed the grazing and ruminating time of animals by recording jaw movements continuously. In addition, a pedometer was used to record walking time. Over the entire experimental period, weather conditions were recorded with an automatic weather station. The maximum temperature value and the minimum relative humidity value, for each day, were used to calculate the temperature humidity index (THI) as reported by Ravagnolo et al. (2000). Based on these data the 10 days of trial were subdivided into period "Hot" (THI $\geq$ 68; no. 4 days) and period "Cold" (THI < 68; no. 6 days). In order to investigate the differences between the behavior of the day and that of the night, every day of trial was split on the basis of sunrise and sunset times. The average length of the night was 11 hours and 32 minutes. Data were analysed considering mixed models for repeated measures where periods (Cold – Hot) and days were treated as fixed factor and repeated measure respectively.

Results Climatic conditions did not affect either the daily or the nocturnal behaviour of dairy cows on the pasture with the only exception of nocturnal ruminating time that was higher in Hot than Cold period ($P<0.05$). Probably the THI of 68 points, which was considered as a threshold of heat stress by Collier et al. (2012), is not sufficient to sharply alter the animals behaviour in these rearing conditions. With similar values, Kendall et al. (2007) showed alterations in body temperature of the cows indicating a possible heat stress.

Table 1 Feeding and locomotion behaviour of dairy cows

	Periods		
	Cold	Hot	SEM
Total grazing time (min/day)	561.5	555.8	11.79
Nocturnal grazing (% grazing time)	40.2	37.3	2.19
Total ruminating time (min/day)	480.6	474.5	8.27
Nocturnal ruminating (% ruminating time)	58.8[a]	62.7[b]	2.92
Total walking time (min/day)	107.7	109.2	4.69
Nocturnal walking (% walking time)	33.0	31.1	0.86

Conclusion The RumiWatch sensor, until now used indoors, was easy to use even under complex experimental conditions. In this study, considering a THI threshold of 68 points, the animals increased the nocturnal ruminating time during hot days without affecting the grazing and walking time.

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Real time location tracking of sheep in grassland systems

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Application Real-time monitoring (RTM) provides many opportunities for management in livestock systems. For extensive grassland systems, knowing where animals are located is critical to being able to act.

Introduction There is considerable experience using Global Navigation Satellite System (GNSS) in research environments - but issues of cost, kit size, power use and data communication and handling are now being overcome to enable real-time management tracking. This study involved initial proof of concept with GNSS collars communicating real-time using low power radio systems. The resolution and accuracy of GNSS derived location can be to a known point, useful to find a sheep/cow that has an identified problem. Farmers in scoping studies identified the utility of knowing and identifying livestock to specific fields (for audit/counting purposes) and receiving live alerts (via smartphone) of any boundaries.

Material and methods Prototype sheep collars containing GNSS technology and low powered connectivity methods were used to log sheep location and transmit data via LoRaWAN (Long Range wide area network). Two non pregnant ewes within a small flock of 12 were fitted with the collars and put into a small field (1.85 Ha), with the field centre 625 metres from the nearest LoRaWAN gateway. The field was not in the optimum 'line of sight' cover by the LoRaWAN antenna, with some buildings and topography creating potential barriers. The two collars were configured to require a minimum of six satellites for location triangulation with data transmission frequency set to either one or five minute intervals over a 14-day trial period. In parallel studies, a smartphone with inclusive GNSS unit using Endomondo, a leisure app for tracking runners and cyclists, was used to collect, and download for later use, the tracks of a person covering either a circuitous 12 km route around fields (they were measuring sward heights for other studies) or climbing a nearby mountain (10.1km line of sight away from the gateway and 850m above sea level. A sheep collar transmitting live via LoRaWAN on a 1 minute cycle was carried at the same time. Data was logged in Zoatracks (http://zoatrack.org/) an on-line analysis site for wildlife tracking, and mapped and analysed in terms of both spatial and temporal patterns.
There were four key questions in to this proof of concept study. Did the GNSS receiver collect appropriately accurate data, was that data communicated live through the LoRaWAN network and could some preliminary analysis of the value of the data for identifying the grazing field in which the sheep grazed? Finally, was remote data satisfactorily communicated and accurate with surrogate (human instead of stock) tracking in more remote locations?

Results Location 'hotspots' linked to both grazing and camping areas for the two collared sheep were in close proximity to the fence line. Spread of data points from a static point with static collars were in excess of 20m (10m from the centre), as a result of standard GNSS error. Methods were assessed to reduce GNSS spread and reduce the potential for incorrect identification of field location. For Sheep 1, with 15976 locations at 1 minute location cycles over 14 days, it was found that 29% of locations were outside the best assessment of the fence line boundary (itself an issue) of the grazing paddock. Using a 10 location rolling average visibly reduced the spread of apparent locations beyond the fence line, but 20% of locations were outside the fence line. Adding a 10m buffer line outside the physical barrier to the raw location reduced the proportion of 'outside' locations to 1.5%. But combining a rolling average and a 10m buffer zone reduced the 'outside' fence line to just 9 locations or 0.05% (1 in 1775) and the numbers of time-consecutive locations outside the fence line was zero. For Sheep 2 with a GNSS cycle of 5 minutes, with 1543 locations over 11 days, 21.3% of raw data points were outside the fence line. By adding a 10m buffer zone, for this sheep and collar, the number of locations was reduced to 1.6%. Using a 10 location rolling average reduced the number outside the fence line to 1.9% and a combination of rolling average and 10 metre buffer zone placed every location within the field. Communication data losses, in the absence of full line of sight, are expected to be under 10% (i.e. 9 out of 10 messages are received by the gateway). The sheep trial demonstrated that 83% of locations were made live in the ascribed one minute cycle, 90% of locations were within a 2 minute cycle. Trials by people acting as sheep surrogates provided no grossly inaccurate location data, with similar data communication loss.

Conclusions Sheep location in practical situations can be achieved using low cost GNSS modules communicating via LoRaWAN. Data from these low resolution modules can allocate sheep to the required field but need multiple locations and some element of data smoothing and/or buffer areas. Real time location requires a run of preceding data points included in any audit. Alerts of fence line breach would be premature based on single data points but require multiple locations to avoid false negatives. To ensure that real time location is useful, these must be frequent. Such geo-fencing applications require multiple triggers prior to alerts. But current technology and resolution of location can be beneficial to farmers.

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Prediction of grass dry matter intake in grazing ewes using infrared thermal imaging

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Application There may be potential to use Infrared thermal imaging of the eye (e.g. average or maximum temperature) to predict grass dry mater intake (GDMI) of ewes.

Introduction Feed cost accounts for 0·70–0·75 of all variable costs incurred on Irish cattle and sheep farms (Connolly et al. 2010). Genetic improvement of feed/production efficiency in ruminants is one avenue to achieving efficiency gains. Unlike feed intake, data on most energy sinks are available or easily attainable (milk yield parameters, live weight, live weight gain). Estimation of feed intake particularly in pastoral systems has historically been a costly and labour intensive procedure (Coleman et al., 2005), and is effectively confined to a research environment. For this reason the ability to generate genetic evaluations for feed/ production efficiency as a direct selection trait has been unattainable. Hence, if recording of feed intake or a suitable proxy was to be developed, a genetic value for feed/ production efficiency as a direct selection trait could follow. Montanholi et al (2009) demonstrated the potential for the application of infrared thermography (IRT) to predict feed efficiency. Consequently, the objective of this study was to establish the efficacy of infrared thermography (IRT) to predict grass dry matter intake (GDMI) of grazing ewes.

Material and methods Grass dry matter intake (GDMI) was estimated on 35 grazing ewes; 17 Belclare crossbred and 18 Suffolk crossbred ewes, using the n-alkane technique. Seven primiparous ewes, 3 second parity, 7 third parity and 18 fourth parity ewes were included in the study. Mean lambing date was 13th March 2015. Belclare and Suffolk crossbred ewes were rearing 1.8 and 1.5 lambs per ewe respectively. Ewes were stocked at 12 ewes ha^{-1} for the duration of the study. Pre and post-grazing sward heights were 8cm and 4.1cm respectively. Lambs were weaned at 14 weeks of age and a leader follower system was operated with a target post grazing sward height of 5.1cm for lambs and 4.1cm for ewes. The GDMI was measured on day 40 (±5.6) and 60 (±5.6) of lactation, and 42 days post-weaning. Intake was averaged over the 3 time points. Thermal images were captured using a FLIR T430sc thermal camera (FLIR Systems Inc., Stockholm, Sweden) 27 and 63 days post-weaning. Thermal imaging is a non-invasive and non-contact heat detecting technology (Knizkova et al., 2007). Images were taken out of direct sunlight. The camera was set to auto-focus mode. The spectral range of the camera ranged between 7.5 and 13 µm. Images of the eye, cheek and rib area, as well as the front and back legs were taken at approximate distances of 0.85m, 0.85m, 1.20m 1.08m and 0.85m respectively. Daily ambient temperature and humidity data were obtained from an on-site weather station. The thermographs were interpreted using Thermovision LabVIEW toolkit 3.3 (FLIR Systems Inc., Stockholm, Sweden). The different body parts had specific shapes outlined using tools within the image analysis software in order to keep a constant sub-area for each body part. Average and max temperature of each body part was computed. Adjustment variables included in the analysis were ewe breed, ewe parity, number of lambs being reared per ewe and lamb gender. Data were analysed using Proc Reg (SAS Inst. Inc., Cary, NC).

Results Mean GDMI of ewes was 2.15 kg. Positive correlations were observed between GDMI and average and max eye temperature with R^2 values of 0.39 and 0.38 respectively; ($P<0.05$). Average eye temperature ranged from 31.9°C to 36.0°C with an average temperature of 34.8°C. Max eye temperature ranged from 34.2°C to 39.1°C with an average temperature of 38.0°C. Average and max temperature of other body parts did not significantly correlate with GDMI.

Conclusion This study demonstrated the potential to predict feed intake in grazing ewes using IRT as a proxy. The results from this study indicate that average and max eye temperature were moderately correlated with GDMI in ewes. This study is part of a large overall study measuring various traits in grazing ewes as predictors of intake.

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A preliminary evaluation of a simple model for the estimation of mountain forage biomass using Sentinel 2 data

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Application Reliable and cheap remote sensing methods for estimating mountain grassland forage biomass are needed to avoid under- or overgrazing and consequent grassland degradation.

Introduction Precision grazing may increase grassland conservation and farm productivity, through improved pasture and animal management. One of the main issue is to estimate the actual productivity of the pasture and its trend over time (Ali *et al*., 2016), in order to program the correct grazing load during the year. The main objective of this study was to evaluate the predictive performance of NDVI (Normalized Difference Vegetation Index) in a mountain environment using red and infrared bands from the Sentinel 2 satellite.

Material and methods During 2016 growing season, in a Central Italy mountain pasture (M. Tilia, Rieti), we built nine grazing exclusion fences (GEF, plots of 12 m x 12 m), coinciding with the Sentinel 2 acquisition grid (10 m x 10 m pixel). Inside each GEF, we cut grass (5 m^{-2}, three sub-plots) once a month for three months. The grass was weighed and analysed for chemical parameters.

At the dates matching with cuts, free-of-charge red and infrared bands were acquired from Sentinel 2 data hub, in order to calculate the NDVI. In a GIS environment, we extract NDVI values for each plot. NDVI was related to field measured biomass (t ha^{-1}) using a simple linear regression.

Results The summary statistics of green biomass dataset (n=27) are reported in Tab. 1. NDVI, varying from 0.41 to 0.83, showed a good linear relationships (Y=18.681X-7.1557, R^2=0.64, SEE 1.59, P<0.001) with green biomass. As expected, a lower relationship (Y=4.1051X-1.0457, R^2=0.47, SEE 0.49, P<0.001) was observed between NDVI and dried biomass. Significant correlation at P<0.5 was found between NDVI and ether extract (P=0.459) and NDVI and Acid Detergent Fibre (P=0.167), however with lower coefficient of correlation (R^2= 0.10 and 0.19, respectively).

Conclusion The simple linear regression model, after being further refined and validated, can be used to spatialise data over vast grazing areas, with high temporal frequency (5-10 days as Sentinel 2 acquisition of images), helping in a more precise planning of livestock grazing. Other vegetation indexes (i.e. REP, SAVI, TSAVI) could be used in order to minimise inaccuracies (e.g.,. mitigating the effects of atmosphere and background reflectance etc.) or to find some possible relationship with chemical composition (i.e. with the nitrogen content).

Table 1 Summary statistics of measured green biomass and chemical composition for the data set

	Mean	Min	Max	Range	Std. Dev.	SDR
Fresh green biomass (t ha^{-1})	5.04	0.15	22.96	22.81	5.13	101.81
Dry green biomass (t ha^{-1})	1.75	0.12	6.13	6.01	1.48	84.64
% DM	43.52	20.86	81.25	60.39	14.56	33.45
Ash (% DM)	5.62	3.17	9.60	6.43	1.40	24.85
Protein(% DM)	9.47	4.90	16.86	11.96	2.80	29.58
Ether extract(% DM)	1.98	1.06	7.14	6.08	0.85	42.89
Fibre (% DM)	33.46	25.22	41.78	16.56	3.33	9.96
Neutral Detergent Fibre (% DM)	60.60	44.40	72.81	28.41	7.36	12.15
Acid Detergent Fibre (% DM)	41.69	26.33	54.24	27.91	5.44	13.04
Acid Detergent Lignin (% DM)	11.76	5.51	19.92	14.41	3.58	30.46
Nitrogen-free extracts (% DM)	49.48	40.98	55.31	14.33	3.32	6.71
Non-structural carbohydrates (% DM)	20.65	6.58	38.43	31.85	7.44	36.02

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Calving behaviour monitoring through Digitanimal platform in dairy cows: Preliminary results

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Application Animal welfare is increasingly important for the livestock. New engineering advances allow the development of “sensing solutions” in an integrated management system as it is provided by Digitanimal collars in extensive farms.

Introduction Digitanimal is a Software as a Service platform that offers location, monitoring, and traceability capabilities for real-time livestock in extensive systems, by using GPS, temperature sensor and three-axis accelerometer activity recorders. Currently, there are increasing interest to develop electronic devices with higher sensitivity and larger data storage capacity for studying animal activity. In addition, acceleration data has been used to monitor cow behaviour as lying, standing and feeding (Vázquez Diosdado et al., 2015). The calving event is announced by typical behaviour patterns of cows in the first stage of labour (Wehrend et al., 2006). In order to predict the calving event by Digitanimal collars, the time cows spent in a behaviour were presented as preliminary action to develop the predictability tool through the accelerometer data-set from Digitanimal tool.

Material and methods The study was carried out in the experimental herd in the Regional Agrifood Research and Development Service (Asturias, Spain). Three Holstein cows were separated in maternity pen when physiological signs indicated imminent parturition. Cows were continuously filmed. Every animal carried a Digitanimal collar on their neck during the study. The collars contained a 3-axis high precision accelerometer and a microcontroller with embedded firmware. A behaviour catalogue was performed including ten conducts: eating, rumination, drinking, grooming, resting, locomotion, contraction, cleaning the bed, placentophagy and calf cleaning. From video observations the behaviour of the animals was recorded by ethograms using two methods, a focal sampling activated each two minutes during seven hours before and after calving and a continuously focal sampling activated by behaviour transition during the hour before and after calving. The percentage of behaviours represents the time in which cows spent performing a behaviour during data collection.

Results The rumination behaviour was the most common during seven hours before calving (29.6%) followed by resting (28.9%), nevertheless, one hour before and after calving the rumination was decreased (0.3%) as other authors reported (Pahl et al., 2014). During seven hours after calving the resting behaviour was the most common (29.1%) followed by rumination (25.2%).

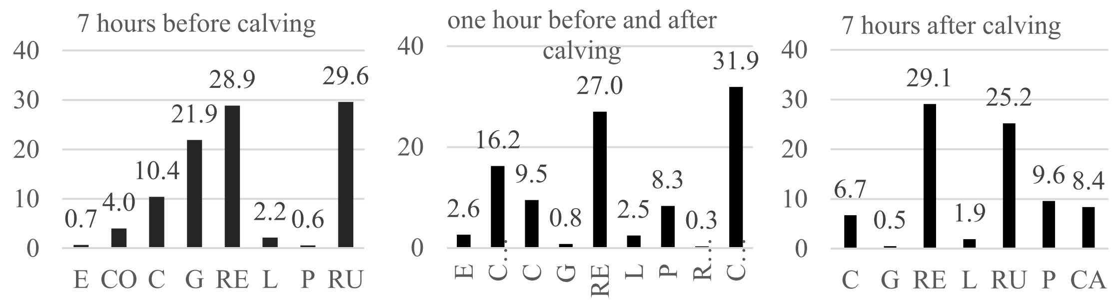

Figure 1 Percentage of time spent in eating (E), rumination (RU), drinking (D), grooming (G), resting (RE), locomotion (L), contraction (CO), cleaning the bed (C), placentophagy (P) and calf cleaning (CA) during the calving event.

Conclusion Taking into account that there is evidence of changes in behaviour pattern that have relation with the movement of the head animals, through Digitanimal collars we will focus in data base from accelerometer that will provide more information to differentiate conducts as resting and ruminating to predict in the future the calving event in grazing cows.

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Grasscheck: weather and grass growth monitoring to improve grassland management in Northern Ireland

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Application The GrazeGro model can be used as a reliable predictor of grass growth. However there is a need to provide a wider spread of monitoring sites to overcome the high variability of weather conditions.

Introduction Grazed grass is amongst the most cost-effective feed-stuffs for lactating dairy cows. Northern Ireland (N.I) is one of the main European regions for grass production. However current performance of managed grasslands in N.I. remains sub-optimal. Forecasting grass growth rates is a useful tool to assist farmers in making grassland management decisions throughout the season. The aims of this study were: (i) to evaluate the use of a grass growth prediction model to forecast 7 and 14 day grass growth rates throughout the grazing season and (ii) to evaluate the variability in grass growth potential across N.I.

Material and methods The study consisted of two experiments. Experiment 1(E1) was conducted between March and October 2016 at two permanent grassland sites in N.I. At each site two sets of 9 plots (5.0 x 1.5m) were established in perennial ryegrass pasture. Each plot was randomly allocated to one of three harvesting sequences beginning on 7 March, 14 March or 21 March 2016. Following this, plots were cut at three week intervals. All plots were assessed for soil fertility and corrected for phosphorus, potash, magnesium and sulphur and received 270kg N/ha per annum. Weekly grass growth was measured by the cut and weigh method. Average daily rainfall, daily air temperature and photosyentical active radiation were inputted to the model on a weekly basis. The forecasted grass growth was calculated using the GrazeGro model (Barrett, et al. 2005) with output modified by herbage mass estimates in the 2-week re-growth monitoring plots. Experiment 2 (E2) started on January 2017 and is currently on-going. A network of 30 weather stations was set up across N.I. Each of the weather stations was installed on commercial dairy and beef farms. The monitoring farms were selected based on location and farming system criteria. The weather stations recorded rainfall, air temperature, soil temperature, soil moisture, wind speed, wind direction and solar radiation; with a 30 minute resolution. Site specific grass growth will be calculated using the GrazeGro model and compared with measured grass growth data.

Results During E1, mean annual rainfall across both sites was 1081 mm and mean monthly air temperatures ranged between 4 and 15°C. Annual herbage yield across the two sites averaged 13.6 tonnes of dry matter per hectare. A linear regression model (Type II) was established between the observed and forecasted grass growth rates (P<0.01, r=0.810), with the model explaining 65% of the variability in grass growth.

Preliminary results from E2 showed that there was a significant effect (P<0.05) of location on soil temperature, air temperature, weekly cumulative rainfall and mean weekly solar radiation (Table 1).

Table 1 Mean County weather parameters for (March 2017) measured across N.I.

	Antrim	Down	Armagh	Fermanagh	Tyrone	Derry	SD
Soil temperature (°C)	7.0^{a}	7.7^{b}	7.3^{ab}	7.3^{ab}	7.1^{ab}	7.3^{ab}	0.24
Air temperature (°C)	7.1^{a}	7.5^{b}	7.3^{ab}	7.3^{ab}	7.1^{ab}	7.1^{ab}	0.28
Weekly rainfall (mm)	15.5^{ab}	8.5^{b}	10.2^{ab}	10.3^{ab}	18.3^{ca}	16.6^{ca}	4.04
Solar radiation (Langley)	1281.1^{a}	1280.6^{a}	1209.6^{ab}	1206.4^{ab}	1339.2^{ab}	1304.5^{ab}	52.74

Note: different letters in the same row indicate values significantly different with P<0.05. Standard deviation (SD).

Conclusion Grasscheck is a useful guide to estimate grass growth rate, providing valuable information to livestock farmers. Initial weather results suggest in order to achieve site specific grass growth predictions, a wider spread of monitoring sites across N.I. is required to overcome the high variability of the weather parameters that influence grass growth.

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Soil electric resistivity at different water levels in an integrated crop-livestock-forest system

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Characterizing the spatial variability of soil properties can be very useful for decision-making in crop management strategies. The aim of this study was to characterize the spatial variability of soil electric resistivity under different soil moisture conditions in integrated systems. The study was conducted in a 9.7 ha-area of integrated systems in San Carlos (SP). Electrical soil resistivity (SR) was measured with a contact sensor on two dates with different soil moisture values. Soil moisture was monitored with a Diviner probe. Maps were obtained using the inverse square of the distance. Electrical soil resistivity allowed us to delimit regions within the study area based on differences in the movement and accumulation of water in the soil horizons. There was a trend for a reduction in resistivity values with increasing soil moisture.
Keywords: soil sensor, soil water content, ARP® system.

Evaluating the critical nitrogen dilution curve in grass seed production using images from an unmanned aerial system

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Denmark is a world leading grass seed exporter that is striving to increase efficiency and modernization of the production system. To further increase the efficiency, while reducing negative environmental impacts, there is a need to introduce precision agriculture technologies in these crops. Our purpose is to develop and implement differentiated nitrogen (N) application maps based on drone-mounted camera (sequoia camera that captures green, red, red edge and near-infrared wavelengths and RGB) in the production system. Most N application maps are based on NDVI values, however, we aim to test the possibility of using the critical N dilution curve that has been developed by Gislum et. al. (2009) to define the N application rate before stem elongation. The first step will be to evaluate the possibility to replace time-consuming plant sampling and analysis of N status and biomass by using images from drone-mounted cameras. Our measurements will be performed in field plot experiments and farmers fields. The results will be shown as regression models developed on information from images and reference plant destructive analysis. Furthermore, we will make an N application map in a farmers' field based on our regression models.

Towards the estimation of vole damage on grassland by aerial multispectral imaging

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Since the early 1970s, vole outbreaks have cause substantial damage in grasslands. Some action plans were developed in order to identify the factors responsible for outbreaks and to propose rational control methods. Our French project aims to develop the use of aerial imagery to detect and prevent damage by moles and voles on grassland. It has been initiated and founded by the FREDON of the Franche-Comté region, which is a professional organisation responsible for monitoring pests of plants.

This paper presents methods to compute the degree of infestation by moles and voles using multispectral images provided by AIRINOV company, pioneer in drone-based farming applications. Their acquisition involved an imaging system embedded in a UAV and composed of four filters, where the spectral bandwidths are in the Red, Green, Red-Edge and Near-Infrared regions. Aerial images of 12 different zones were acquired (3 in 2014, 3 in 2015, and 6 in 2016). The images acquired in 2014 and 2016 show breeding areas with terrestrial vole damage, whereas those acquired in 2015 describe field vole damage. In 2016, the visible damage was located by a pedestrian observer using a GPS receiver.

We propose methods based on the use of the Normalized Difference Vegetation Index. First, for each breeding area and field, we compute a mean NDVI value, which is considered as an overall estimate of the state of the area. Second, we estimate the amount of damage with an image analysis (segmentation, mathematical morphology operations, detection of connected components, and filtering on size). Results are presented and discussed regarding to the rates commonly estimated by observers. The performance of the method is evaluated according to the type of grassland (meadow or pasture) and the type of pest (mole, terrestrial vole, or field vole).

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Non-destructive monitoring of grassland canopy height using a UAV

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Grasslands cover one third of the agricultural area in Europe and provide a substantial part of the ruminant feed requirements in the dairy and meat industry. Furthermore, these ecosystems are very effective in preventing soil erosion, building soil fertility, require minimal pesticide use, and contribute multiple positive effects on the environment. Permanent grasslands, and the species they contain, have evolved spontaneously to adapt to the pedo-climatic conditions in which they occur. Hence, these different ecotypes are crucial in breeding under climate change scenarios. One of the main component species in North-West European grasslands is *Lolium perenne* (perennial ryegrass). Due to its rapid growth and establishment, high yield potential and feed quality, perennial ryegrass is also the most frequently sown grassland species in Europe.

We are currently developing a methodology, based on the use of unmanned aerial vehicles (UAVs) combined with different (spectral range) sensors, to monitor perennial ryegrass growth in a non-destructive way. The field trial used for this is located in Merelbeke (Belgium), and is part of GrassLandscape, a FACCE-JPI ERA-NET+ project. In this trial, 500 accessions sampling the natural diversity of the species across Europe and North Africa are grown in replicated micro-swards. As this set of accessions displays a very broad range of genetic and phenotypic diversity, including growth characteristics, it is an ideal target for the development of the methodology. In addition, the results obtained are directly useful to describe the growth characteristics of accessions adapted to different climatological conditions and their value for breeding purposes.

Frequent flights at low altitudes are performed to collect RGB imagery at high spatial and temporal resolution throughout the growing season to estimate canopy height and its temporal evolution. These data are combined with manual on-field measurements of canopy height, performed with an Herbometer, for validation. Correlations between the UAV data and on-field measurements will be calculated to determine the robustness and applicability of the methodology. Finally, canopy height data derived from UAV flights in combination with vegetation indices will be used to estimate the biomass volume and yield.