Project number: 6829
Funding source: Era Net ICT-Agri
December 2020
Project dates: Feb 2017 – Oct 2020

Development of ground based and Remote Sensing automated ‘real-time’ grass quality measurement techniques

Key external stakeholders:
Irish dairy farmers, Consultancy agencies

Practical implications for stakeholders:
This research project work has firstly, benchmarked state of the art grass measurement practices and the level of heterogeneity within Irish grazed pasture. Secondly, state of the art technologies for measuring grass quantity and quality were optimized in terms of measurement precision. Thirdly, NIRS calibrations were developed to predict quality parameters, dry matter (DM, g/kg) and crude protein (CP, g/kg DM), in fresh un-dried grass. Fourthly, the Grass Measurement Optimization Tool (GMOT) was designed to generate measurement protocols that optimize for both time and accuracy. Finally, two Remote Sensing technologies were assessed, Spaceborne Sentinel-2 and the Sequoia Multispectral sensor attached to an Unmanned Aircraft System (UAV); this represents significant progress in the use of alternative technology for grassland measurement/ management.

Main results:

- This study investigated spatial variation of herbage mass (HM) within pastures, determined the number of RPM measurements required to accurately predict mean HM, and assessed the precision of the RPM in terms of measurement repeatability. Pasture heterogeneity varied by 36%; mean CSH could be estimated to within 5% by recording 24 measurements per ha. The standard deviation of RPM measurement repeatability was 4.34 mm.
- The next study aimed to utilize grassland management and climate data, in addition to RPM measurements, to improve the accuracy of HM prediction by means of multiple linear regressions. The addition of farm specific meteorological variables including soil temperature, precipitation and evaporation resulted in a further 4% decrease in variation. But this would not be practical, considering the expense of farm specific meteorological sensors.
- Further work involved developing NIRS calibrations to predict quality parameters, dry matter (DM, g/kg) and crude protein (CP, g/kg DM), in fresh un-dried grass. High predictive precision was achieved for DM and moderate precision for CP.
- The Grass Measurement Optimization Tool (GMOT) was designed to generate measurement protocols that optimize for both time and accuracy. Optimal measurement value was achieved by performing 8 measures per ha and further increasing the measurement rate resulted in diminishing returns.
- An alternative technology of multispectral sensing was carried out using an Unmanned Aircraft System (UAV) and data from the EU Sentinel 2 satellite were also acquired. Grass biomass was estimated at a reasonable level by processing Sentinel-2 and Drone multispectral data using PLSR and at a moderate level using stepwise MLR. The prototype GrassQ web platform is now operational.

Opportunity / Benefit:

The main benefits of the research study were:

- State of the art measurement technologies for fresh grass quantity and quality have been optimised
- Grass measurement benchmarks have been set in terms of both accuracy and methodology

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- The grass measurement optimization tool (GMOT) has been developed to optimize time and accuracy
- The way has been progressed for more regular, automated, low-cost UAV mapping/monitoring of grasslands
- This body of work will facilitate the development of future precision agricultural technologies for pasture-based livestock production.

Collaborating Institutions: Cork Institute of Technology, University of Maynooth

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External collaborators: Michael Murphy, Cork Institute of Technology, Tim McCarthy, University of Maynooth

1. Project background:

Maximizing pasture utilization through optimal grassland management is vital in terms of ensuring the economic sustainability and mitigating the environmental impact of both Irish and global pasture-based livestock production. Frequent and accurate measurement of grass quantity and quality is one of the main methods of maximising grass production and utilisation on pasture-based farms. The most prominent grass measurement tool used on Irish pasture is the rising plate meter (RPM), however, some issues needed to be addressed, e.g. operator bias, precision and difficulties in accounting for spatial variation. A definitive protocol for grass measurement was required, which farmers could follow to objectively measure their pastures and to account for the variation of grass growth within paddocks. Furthermore, there was no rapid method of estimating the quality of grass within pasture. This body of work aimed to optimise state of the art grass measurement technologies through investigation, field experimentation and numerical simulation.

2. Questions addressed by the project:

- Need to optimize state of the art grass measurement technologies through field experimentation and numerical simulation
- Requirement to determine the variation in herbage mass (HM) within grazed swards and evaluate the precision of the RPM for measuring HM
- Optimization of the HM prediction accuracy of the RPM by investigating the utilization of additional grassland management and meteorological data
- Development of a near infrared spectroscopy (NIRS) calibration to more rapidly predict the quality of fresh grass in terms of dry matter
- Development of a grass measurement optimization tool (GMOT) to accurately and efficiently measure grazed pastures.
- Investigation of the alternative technology of multispectral sensing

3. The experimental studies:

The first study determined the variation in HM within grazed swards and evaluated the precision of the RPM for measuring HM. Intensive compressed sward height (CSH) measurements and HM reference cuts were carried out on trial plots and grazed paddocks at Moorepark, Ireland over two grazing seasons. Retrospective analysis simulations were performed in order to calculate the effect of various reduced measurement resolutions on estimated mean CSH error. A repeated measurement analysis was performed on grass samples to determine RPM system error.

The second study focused on optimizing the HM prediction accuracy of the RPM by investigating the utilisation of additional grassland management and meteorological data using multiple linear regression in combination with backward sequential variable selection, all subsets regression and k-fold validation. Monthly regression models were created from a selection of 17 variables with data collected over two grazing seasons.

In the third study, a near infrared spectroscopy (NIRS) calibration was developed to enable more rapid prediction of the quality of fresh grass in terms of dry matter (DM) and crude protein (CP) content. Perennial ryegrass samples (n = 1,812) were collected over three grazing seasons and scanned using a FOSS 6500 spectrometer to develop NIRS calibration and validation datasets. Reference wet chemistry analysis was carried out for DM and CP and the resultant data were calibrated against spectral data by means of modified partial least squares regression.

The fourth study involved development of a grass measurement optimization tool (GMOT) to accurately and efficiently measure grazed pastures.

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The final study involved an alternative technology of multispectral sensing; data was collected using a Sequoia Multispectral sensor attached to an Unmanned Aircraft System (UAV) and the EU Sentinel 2 satellite. Data was also collected at Moorepark over 18 month, at varying intervals to match dates when grass-sample cutting and laboratory analysis was carried out. Overall, five sets of ground based samples were used to develop prediction models of grass biomass using the multispectral imagery (Sentinel-2, Drone).

4. Main results:

Within the first study, the value of HM within swards was found to vary on average by 36%. Factors that affected sward heterogeneity were identified as nitrogen fertilisation, clover content, morphology and seasonality and grazing effects. Mean CSH could be estimated to within 5% error using the RPM by recording 24 measurements per ha in a random stratified manner. Recording ≥ 40 RPM measurements per ha resulted in a diminishing rate of returns in terms of reducing mean CSH estimation error. Measurement system error for the RPM, in terms of the standard deviation of measurement repeatability, was calculated to be 4.34 mm.

In the second study, reductions in HM prediction error of 20 – 33% (root mean squared error) were achieved in comparison to state of the art models used on Irish pastures. The inclusion of meteorological variables slightly improved HM prediction performance however, this improvement was not sufficient to warrant the investment in on-farm meteorological sensors. The optimum model utilised variables CSH, N fertilisation rate and grazing rotation number and is suitable for integration with grassland decision support software currently used on Irish farms.

In the third study, the ratio of percentage deviation (RPD) was used to rank the developed NIRS calibrations, which were sufficiently precise to replace laboratory oven drying methods for DM (RPD =2.63) and were capable of categorising the quality of pasture in terms of CP (RPD = 2.37). These calibrations have the potential to reduce laboratory costs, streamline herbage quality analysis and may be used for benchmarking future grass sensing technologies.

In the fourth study, the developed prototype was a Visual Basic Application for MS Excel decision support tool that generated interactive paddock measurement guide maps. Farmers could use the GMOT to create optimised protocols for measuring their pastures in a random stratified manner based on GPS co-ordinates, resulting in accurate non-biased estimations of sward parameters. Measurement routes were optimised using a genetic algorithm based on a traveling salesman problem. Actual survey error was estimated using Monte Carlo simulations that combined measurement and calibration error distributions generated from data collected as part of objectives 2 and 3. Actual error was estimated to 28.1% (relative prediction error) for the RPM and the optimum measurement rate that minimised both cost and error was 8 measurements per ha. The GMOT was developed to generate objective spatially balanced and geo-tagged grass measurement protocols that could be used for a range of pasture measurement methods, including quality analysis. So GMOT outputs included predicted measurement survey value, cost, error and time. These findings could be combined into an easy to use grass measurement protocol that would enable farmers to optimise grass measurement time and labour in accordance with precision.

In the final study, grass biomass was estimated at a reasonable level by processing Sentinel-2 and Drone multispectral data using PLSR and at a moderate level using stepwise MLR. Parallel work in Finland, showed estimations for grass silage swards using Random Forest (RF) analysis with 3D features and based on point cloud and image spectral features, indicated R2 values similar to Ireland.

5. Opportunity/Benefit:

The findings of this study will allow grass measurement protocols to be optimized. Specifically, the GMOT outputs enabled optimal grass measurement of pasture by performing 8 measurements per ha in a random stratified manner using the RPM. Cost benefit analysis of GMOT outputs showed a diminishing rate of returns in net measurement value when performing more than 8 measurements per ha. The GMOT is applicable to a range of pasture measurement technologies. Furthermore, these optimized measurement protocols are ready for integration with online decision support tool technologies for use on Irish grasslands. This will facilitate the availability of frequent and accurate pasture quantity and quality information to farmers that will enable precise allocation of herbage to the grazing herd based on their dietary requirements.

6. Dissemination:

Main publications:

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Murphy, D.J., O' Brien, B., Murphy, M.D. (2020). Development of a grass measurement optimisation tool to efficiently measure herbage mass on grazed pastures. Computers and Electronics in Agriculture, 178; https://doi.org/10.1016/j.compag.2020.105799.
Murphy, D.J., O' Brien, B., Hennessy, D., Hurley, M., Murphy, M.D. (2020). Evaluation of the precision of the rising plate meter for measuring compressed sward height on heterogeneous grassland swards. Precision Agriculture; https://doi.org/10.1007/s11119-020-09765-9.
Askari, M.S., McCarthy, T., Magee, A. and Murphy, D.J. (2019). Evaluation of Grass Quality under Different Soil Management Scenarios Using Remote Sensing Techniques. Remote Sensing11(15), 1835; https://doi.org/10.3390/rs11151835.

Popular publications:

Murphy D.J., O'Brien B. and Murphy M.D. (2018). Development of an optimum grass measurement strategy for precision grassland management. Paper presented at the 27th General Meeting of the European Grassland Federation, Cork, Ireland, pp. 883-885.
Murphy D.J., O' Brien B. and Murphy M.D. (2018). Development of a Labour Utilisation Decision Support Tool to Efficiently Measure Grass Herbage Mass Using a Rising Plate Meter. Paper presented at the 2018 ASABE Annual International Meeting, Detroit, MI, pp. 2-8.
Kaivosoja J., Niemeläinen O., Näsi R., Burke R., McCarthy T., O'Brien B., Honkavaara E. 2019. Evaluation of remote sensing technologies and cloud services to support grassland management. Proceedings of the European Conferance on Precsission Livestock Farming University College Cork, pages 204-209.
Murphy D.J., O' Brien B., O' Donovan M., Condon T., Claffey A. and Murphy M.D. (2019). A preliminary near infrared spectroscopy calibration for the prediction of un-dried fresh grass quality. Proceedings of the European Conference on Precision Livestock Farming, University College Cork, pages 199-203.
Hart, L., Oudshoorn, F., Latsch, R. and Umstatter, C. 2019. How accurate is the Grasshopper system in measuring dry matter quantity of Swiss and Danish grassland. Proceedings of the European Conference on Precision Livestock Farming, University College Cork, pages 188-193.
O' Brien B., Murphy D.J., Askari M.S., Burke R., Umstätter C., Hart L., McCarthy T. (2019). Modelling precision grass measurements for a web-based decision platform to aid grassland management. Proceedings of the European Conference on Precision Livestock Farming, University College Cork, pages 858-863.

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