Grass Measurement Optimisation Tool (GMOT) User Manual

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1. Introduction

The grass measurement optimisation tool (GMOT) is designed to optimise grass measurement practices on livestock grazing platforms by increasing measurement precision and curtailing sampling time and effort. The aim of the GMOT is to promote regular and precise grass measurement on grazing platforms; therefore increasing annual fresh grass utilisation and sustainability within grass based livestock industries. The GMOT generates optimum grass measurement protocols in the form of interactive paddock maps that identify target sample locations, which are randomly distributed in a spatially balanced manner. The generated target sample locations are distributed in a manner that allows for spatial variations in sward parameters to be accurately predicted. The protocol route between the target sampling locations is then optimised so that the distance travelled by the operator is minimised. Additionally, the GMOT predicts mean pasture herbage mass (HM) and HM measurement precision, using in-built calibrations and stochastic error simulation models. The main outputs from the GMOT include euro per hectare (€ ha^{-1}) estimations of grass measurement protocol cost in terms of time, effort and measurement error, along with a prediction of overall protocol value based on the potential feeding value of the measured grass. GMOT survey cost and value outputs were designed to outline the benefits of optimal grass measurement in a clear and concise manner that can be easily interpreted by researchers, advisors and farmers.

The GMOT was initially developed over a three year period at the Tegasc Animal and Grassland Innovation Centre in Moorepark Ireland, on cool temperate perennial ryegrass pastures using a rising plate meter (RPM), however, the theoretical framework behind this tool can be applied to any pasture type and measurement system. A demo version of the GMOT can be accessed through the following link: https://messo.cit.ie/gmot.

The first section of this user manual focuses on describing how the GMOT works with a brief overview of the science and statistical analysis behind it. The latter section contains a user friendly step by step guide that shows the user how to create and customise optimum grass measurement protocols using the GMOT.

2. How the GMOT Works

Firstly, the GMOT utilises basic pasture management and geo-spatial information to develop spatially balanced and non-biased grass measurement protocols by a method known as random stratified sampling. Protocols are designed to accurately predict the spatial and temporal variation of grass quantity and quality within grazed pastures. Secondly, measurement time and effort is minimised by an optimum route finding algorithm built into the GMOT, which calculates the shortest route between each spatially balanced sample location. This ensures that even coverage of the pasture is sampled within a minimum time frame. Furthermore, the random stratified sampling regime generated by the GMOT ensures that data gathered at each sampling location can be treated as independent variables. This enables accurate objective predictions of mean pasture parameters values and sward heterogeneity to be determined using established statistical methods. The GMOT can be used to predict pasture HM and HM measurement error to optimise herbage allocation to the grazing herd, which is performed by in-built HM calibration and stochastic error simulation models. Error values are estimated as percentage of the mean predicted HM. At present, the HM models built into the GMOT are specifically for the RPM, however these may be updated for a range of grass measurement technologies in the future. Finally, measurement distance, calibration and error outputs are combined to estimate overall survey costs and value in terms of € ha^{-1}. This enables the user to intuitively customise their sampling protocol to optimise for accuracy, effort and time.

2.1 GMOT Inputs

Firstly, paddock GPS coordinates are uploaded onto the GMOT to create an interactive paddock map, the user can then specify desired paddock entry and exit points and the desired number of measurement samples, which impacts the level of measurement accuracy. The GMOT then divides the paddock into a specified number of even strata of equal areas and assigns an even number of randomly distributed target sample locations within each stratum. This insures that no preference or bias is made in selecting each sample location, therefore removing operator subjectivity. Once the sample locations are assigned to the paddock, a random sampling route between each location is generated. The route is then ordered in terms of each sample locations co-ordinates and subsequently the route distance is minimised by means of a built-in route optimisation algorithm. This process is described in more detail in section 2.4. It is recommended that a protocol be re-generated for each new survey to ensure that the selected sample locations remain random and non-biased. All GMOT input and control buttons are highlighted in the graphical user interface (GUI) outlined in Figure 2.1. A set of default paddock co-ordinates and details come preloaded with the GMOT for demonstration purposes. Administration access is required to change the default paddock co-ordinates on the GMOT demo. Additionally sward and seasonal specific HM calibration options can be selected and inputted in the 'Measurement Protocols Details' section of the GUI including; estimated/measured mean CSH, target post grazing height, HM calibration and measurement month. There are a number of default HM calibrations uploaded to the GMOT basis on research performed in Murphy et al., (2020c). The selected HM calibration and measurement rate directly impact the stochastically simulated error estimations outlined in the 'Pasture Estimations' section of the GUI, which are ultimately used to predict the survey error cost.

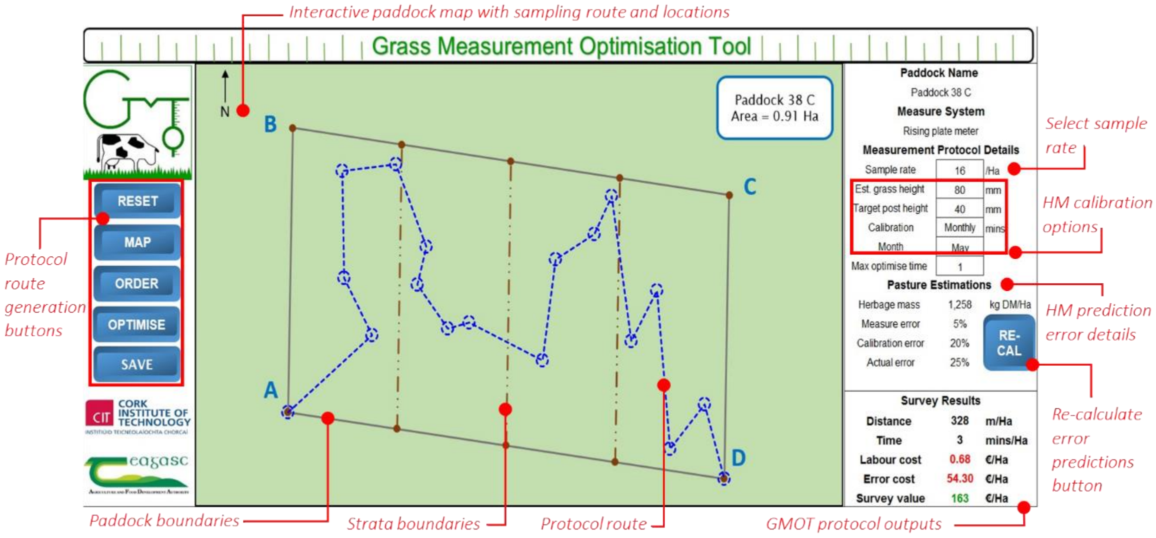

Figure 2.1 GMOT interface with input and output cells highlighted

2.2 GMOT Outputs

Once a protocol is generated, the user is then presented with survey results outputs, highlighted at the bottom right hand corner of the GUI in Figure 2.1, including; survey route distance and time, measurement labour and error costs, and overall survey value. Survey distance, time and labour cost are calculated on the basis of the protocol route distance. Distance is factored by the average human walking pace to predict measurement time, which in turn is factored by the average dairy labour unit wage (€15 hr^{-1}) to predict measurement labour cost. Values for walking pace and cost can be adjusted within the GMOT settings. The overall HM measurement error cost is estimated on the basis of predicted CSH measurement error and HM calibration error. Predicted measurement error in terms of the estimating average compressed sward height (CSH) within a pasture is generated by a stochastic model, which is dependent on the selected sampling rate. Both sample rate and CSH error are interlinked and estimated on the basis of the relationship shown in Figure 2.2, which was developed as part of research that was conducted at Moorepark over a three year period (Murphy et al., 2020b). The HM calibration error is further stochastically predicted on the basis of HM calibration error outlined in Murphy et al., (2020c). The predicted errors are expressed as a percentage of the measured HM and are outlined in the 'Pasture Estimations' section in Figure 2.1. Further detail on the calculation of the survey error cost generated by the GMOT is outlined in Murphy et al., (2020a). Survey value is estimated on the basis of the potential feeding value of the predicted HM, outlined in the 'Pasture

Estimations' section, minus predicted measurement error. The predicted HM is generated from the measured/estimated CSH value, which is factored into the selected HM calibration. The default value placed on each kg of HM measured is 0.173 € kg^{-1} ha^{-1}, based on research performed by Hanrahan et al., (2018).

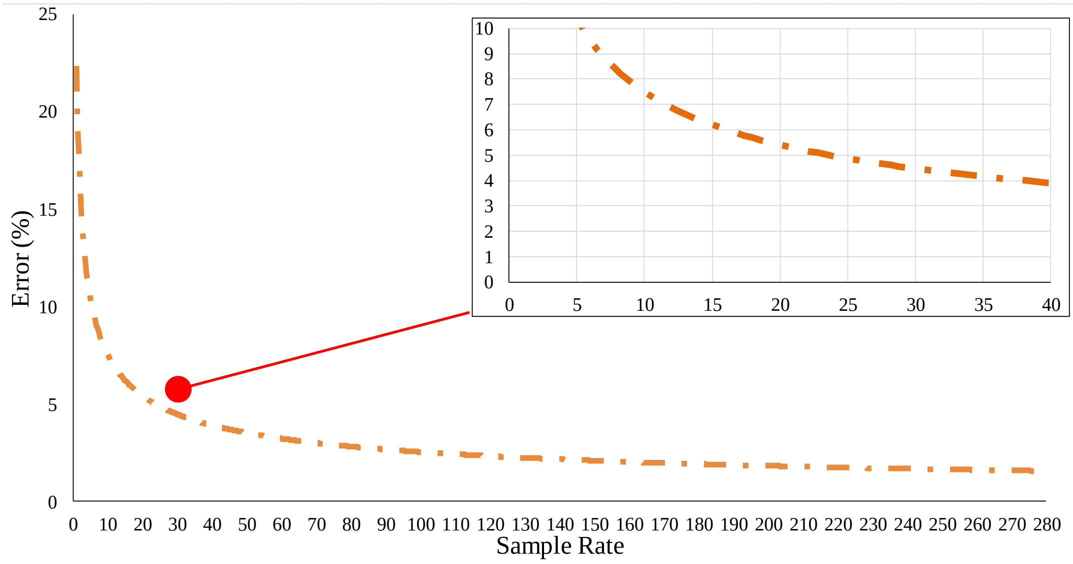

Figure 2.2 Sample rate vs average CSH prediction error relationship developed by Murphy et al., (2020b)

A summary of the protocol optimisation outputs can be saved and viewed by selecting the 'Save' button on the GUI, as seen in Figure 2.3, which saves a summary of the outputs for each stage of the protocol design. Benefits of the GMOT are highlighted by summary charts for protocol time and value. Additionally, a map of the optimised protocol route is further included along with the ITM co-ordinates of each sample location.

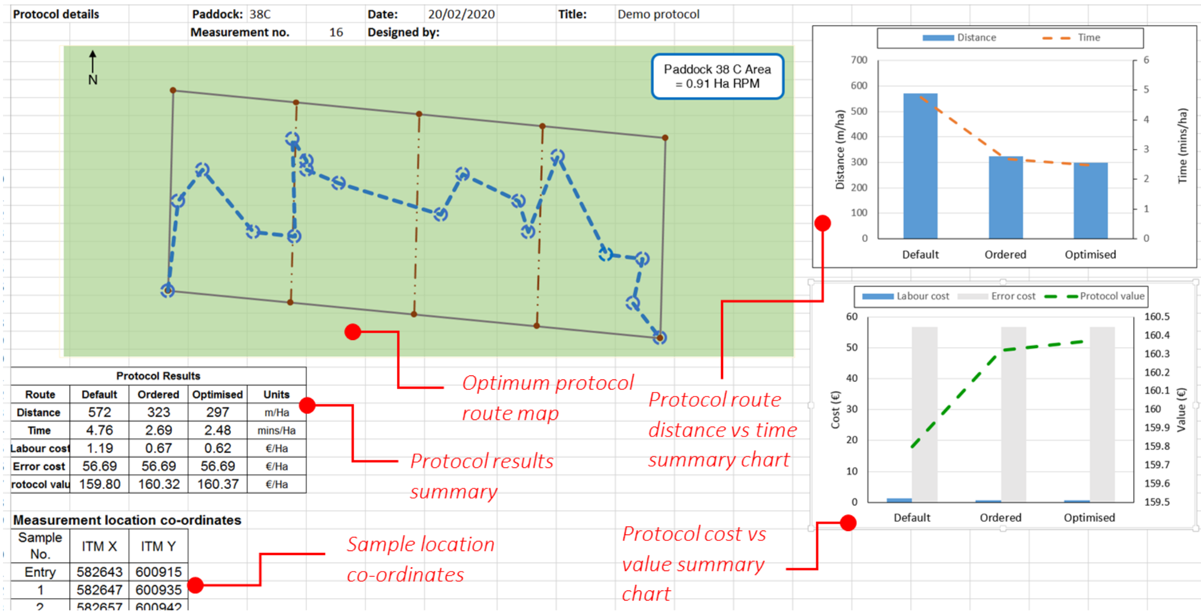

Figure 2.3 GMOT save protocol output summary tab

2.3 GMOT Benefits

The main benefits of the outputs from the GMOT include removing operator subjectivity and increasing the precision of both grassland measurements and management. By using the GMOT a farmer can estimate how accurate their pasture measurements are, enabling them to account for margins of error when allocating areas of herbage to the grazing herd. Furthermore, a farmer can accurately predict the time inputs required to perform a grass measurement walk and allocate sufficient time in their weekly schedule to achieve a desired level of measurement accuracy. Additionally, GMOT outputs enable grassland measurement surveys to be outsourced at a price based on predicted time, effort and accuracy. Moreover, using the GMOT will ensure that a hired contractor follows a predetermined protocol to maintain measurement standards and accuracies. The GMOT makes assessing the overall value of grass measurement possible, as total survey cost generated by the GMOT is the combination of labour unit wage, survey time, predicted measurement error and HM calibration error. Survey cost can then be compared against the value of HM measured, as a guideline to estimate if a survey is financially viable. The developers of the GMOT hope that this tool will outline the value of accurate and efficient pasture measurement to famers and aid the promotion of more precise pasture measurement, management and utilisation.

Although the GMOT is capable of being used in conjunction with any grass measurement system it has in-built features for the RPM, for which it was initially designed. Custom HM prediction equations can be uploaded to the GMOT and seasonal, regional and sward specific models can be selected from the

HM equation drop down menu in Figure 2.1 for different pasture types. Height data for each pasture, namely pre and post CSH, can be inputted into the GMOT so that HM estimates can be derived and combined estimates of HM prediction accuracy and sampling precision can be made to determine overall survey accuracy. Prediction models for other grass measurement systems can also be uploaded onto the GMOT upon request to the developers.

2.4 GMOT Route Optimisation Process

The GMOT generates sampling protocols that optimise for both sampling precision and time. There are three stages in the sample route optimisation process. The first stage optimises for precision by creating non-biased target sample locations in a spatially balanced manner, by allocating an equal amount of random sample locations to each of the evenly sized strata. This ensures that maximum coverage of the spatial variation of the sward can be achieved in a non-biased manner that allows for sampling error to be estimated accurately. Secondly, a piecewise algorithm is employed to order the protocol route in term of the latitude of each targeted sampling location, which reduces the route distance by removing any crossover points. Finally, a built-in meta-heuristic route optimisation algorithm is used to further refine the ordered protocol route to further minimise route distance. The route optimisation process is based on a genetic algorithm that simulates evolutionary processes in the natural world to search a computationally large solution space to find an optimal route selection. Route optimisation is a computationally exhaustive process. For example, sampling at a rate of 16 measurements ha^{-1} results in 16! (2.09×10^{13}) possible optimum route solutions. A significant amount of computer processing power is required to attempt this problem and the user is advised that the GMOT optimisation process can take several hours on conventional computers depending on the number on samples selected (Note: Average CPU processing time to run the optimisation process, on a computer with a Intel Xeon(R) 2.3 GHz processor and 128 GB RAM, ranges from 2.81 hrs at 8 measures ha^{-1} to 5.01 hrs at 32 measures ha^{-1}). For practical use the optimisation time can be constrained by selecting a max simulation run time limit in the drop down indicated in Figure 2.4 below, however, this may result in less optimum route solutions. To ensure an optimum route selection the 'reach converged solution' should be selected.

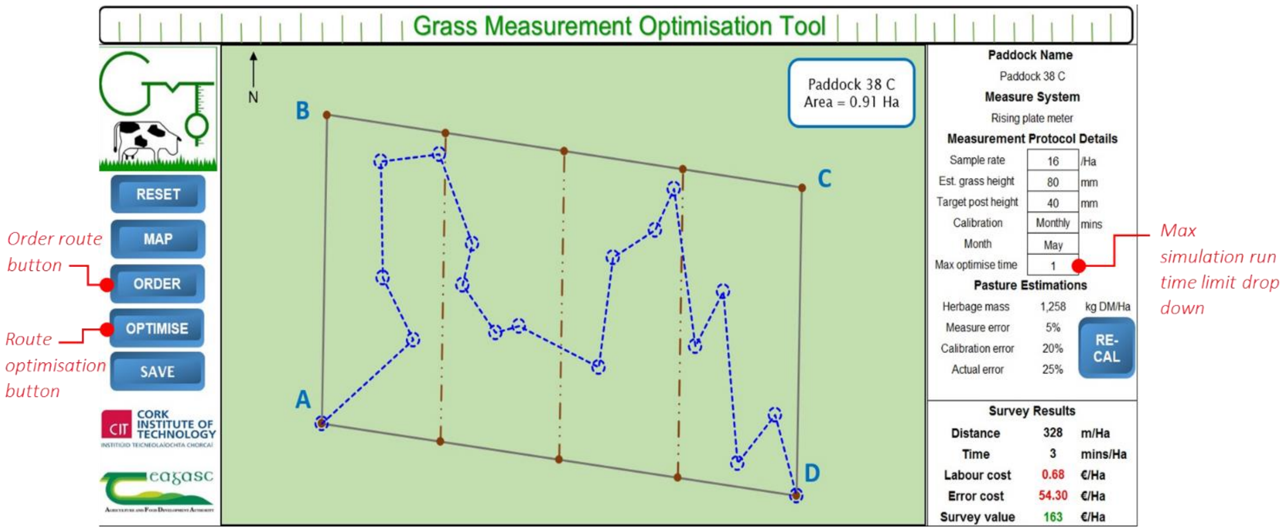

Figure 2.4 Screenshot of GMOT optimisation controls

3. Step by Step Guide

1. GMOT download and set up – There are two versions of the tool for both Microsoft Excel 2013 and 2016 (64-bit Operating System). Download the version that is compatible to the software package on your computer. The GMOT requires Macros to be enabled in excel and the Solver Add-in to be loaded, instructions for both can be found at the following links: https://support.microsoft.com/en-us/office/enable-or-disable-macros-in-office-files-12b036fd-d140-4e74-b45e-16fed1a7e5c6; https://support.microsoft.com/en-us/office/load-the-solver-add-in-in-excel-612926fc-d53b-46b4-872c-e24772f078ca

2. Starting the GMOT – The GMOT will open on the GMOT interface tab (Figure 2.1), this is the only tab required for running the tool. Upon opening the GMOT Demo there will be preloaded co-ordinates for a generic paddock, which can be used for demonstrating the tool's capabilities.

3. Specifying sample protocol details - Firstly select the desired sample rate ha^{-1} 'Measurement Protocol Details' section, then input the estimated pre and post-grazing heights (pre-grazing height can also be entered retrospectively once measured). In-built herbage mass prediction calibrations can be selected from the calibration drop down list. Measurement protocol inputs are highlighted within the 'Measurement Protocol Details' section of the GMOT interface in Figure 3.1.

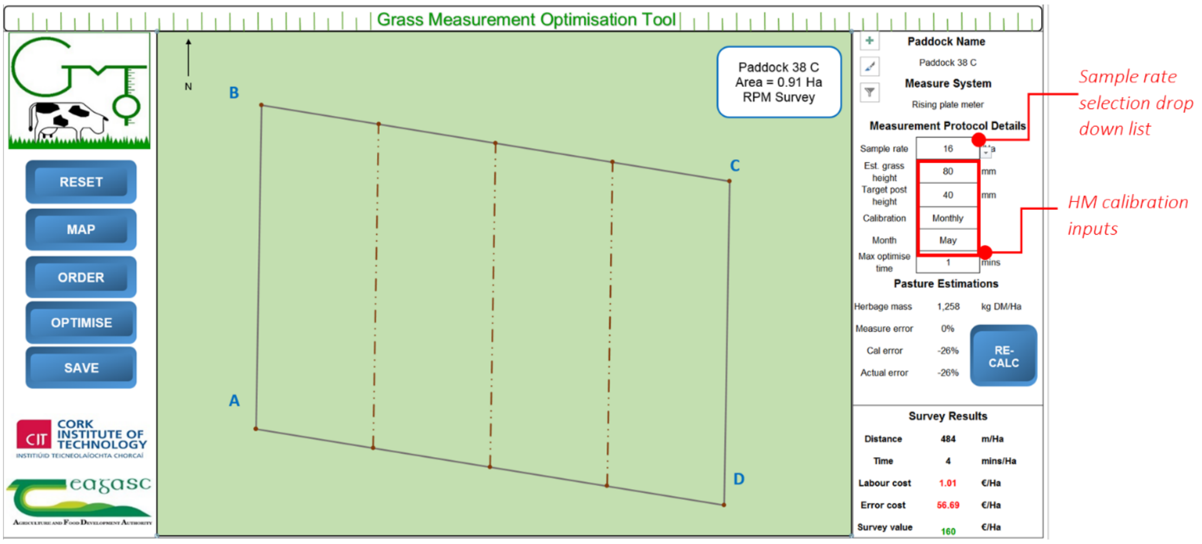

Figure 3.1 Protocol input details

4. Select the 'Map' button to create an interactive random stratified sampling map for the paddock with sampling locations illustrated by **blue** circles. The walking route is indicated by the broken **blue** line and is initially a random route. Predicted protocol outputs can be viewed in the 'Survey Results' section indicated in Figure 3.2. Outputs include; protocol route distance, measurement time, measurement cost and estimated protocol value.

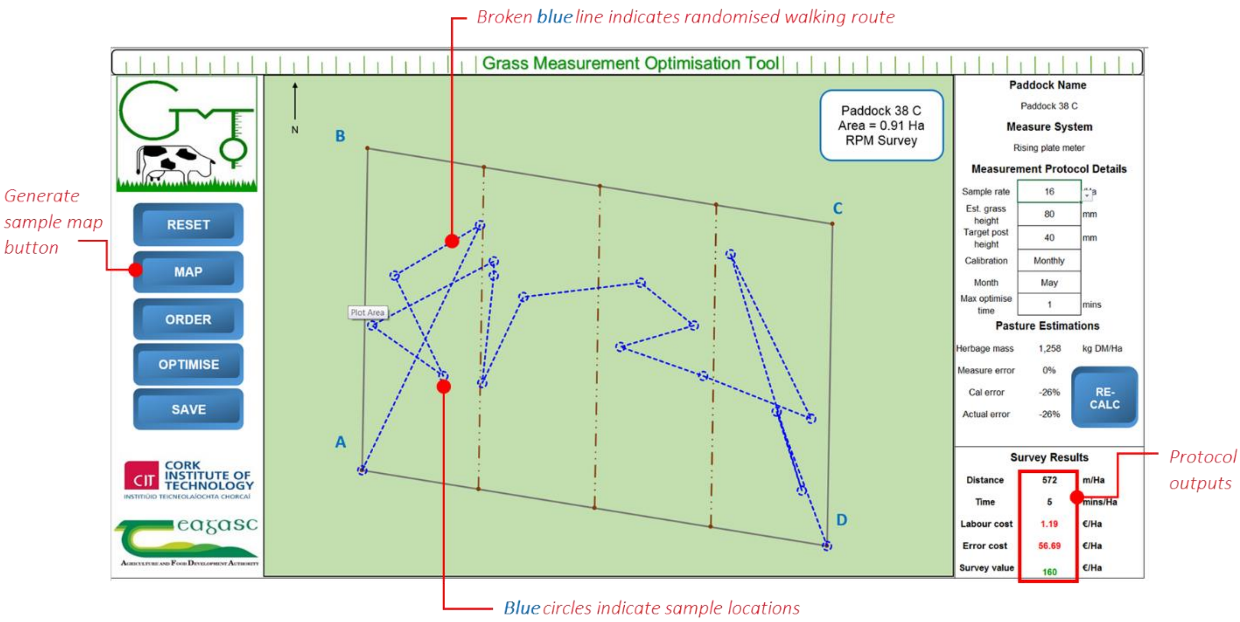

Figure 3.2 Randomised sampling protocol and outputs

5. The ‘Order’ button can then be selected to order the protocol route from paddock entry to exit point according to the latitude of each sample location. A considerable reduction in walking distance and time may be seen in the ‘Survey Results’ section once this is done (Figure 3.3).

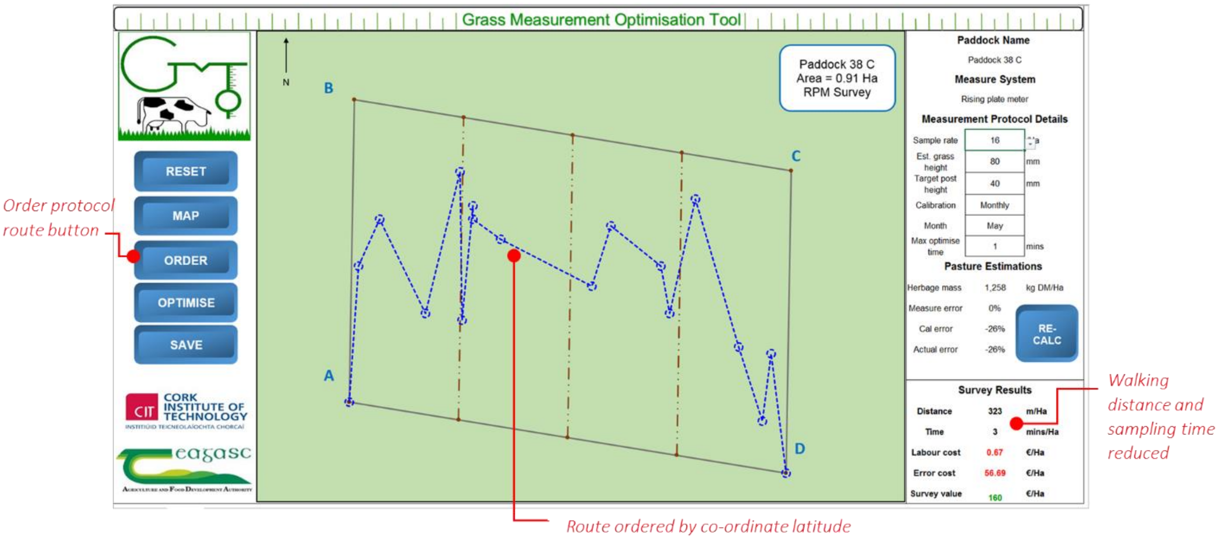

Figure 3.3 Ordered protocol route with reduced distance

6. The final step in generating the sampling protocol is achieved by selecting the ‘Optimise’ button. This activates the in-built route optimisation algorithm to determine the optimum route from start to finish point that encompasses all sample locations and minimises route distance (**Caution!** The optimisation process can take a considerable amount of time, particularly at higher sampling rates as the problem becomes more computationally expensive). Route optimisation time can be curtailed by selecting a max optimise time limit from the drop down menu indicated in Figure 3.4, however, this may have adverse effects on the precision of the optimisation process and may not result in an optimum route selection. Once the optimisation process is complete the optimised protocol route appears on the protocol map, along with any further reductions in distance and time in the ‘Survey Results’ section.

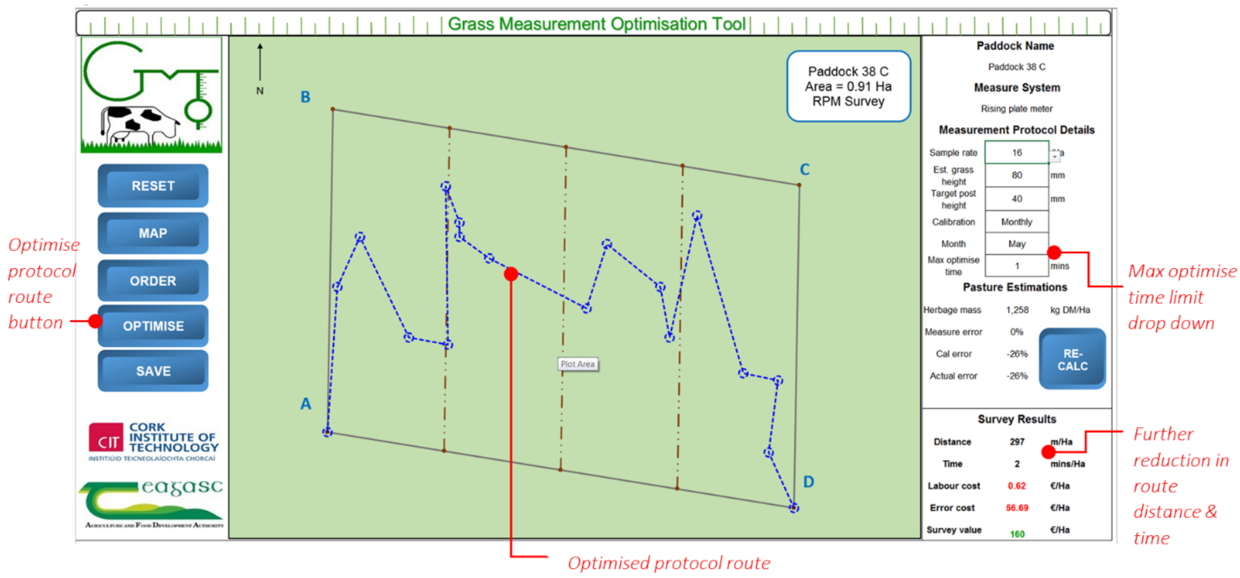

Figure 3.4 Optimised sampling route with finalised sampling protocol

7. The GMOT optimised protocol map and results can now be saved by selecting the 'Save' button (Figure 3.5) and further used to guide pasture measurement. Operators can use the GMOT map to follow the optimum measurement route to each of the generated target sample co-ordinates in the field. Sample location co-ordinates can be downloaded from the GMOT to a GPS system for in-field geo-referencing. Details of the optimisation process and sample co-ordinates are saved in the results tab, as seen in Figure 3.6.

8. Once an optimised protocol has been saved the GMOT can be reset to create a new protocol by selecting the reset button highlighted in Figure 3.5.

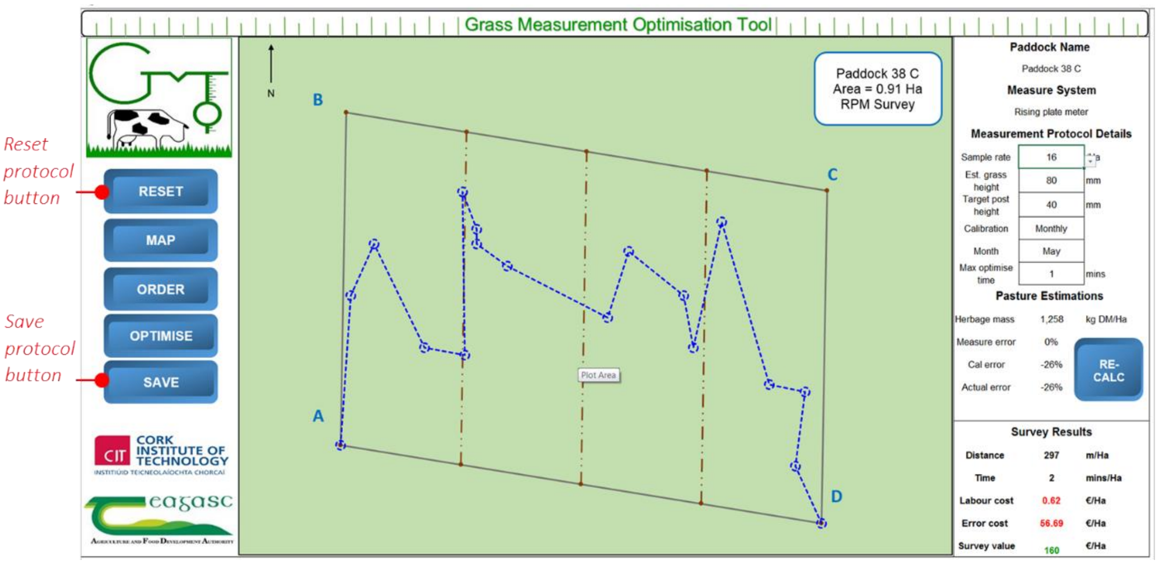

Figure 3.5 Optimised sampling route with 'Save' and 'Reset' buttons outlined

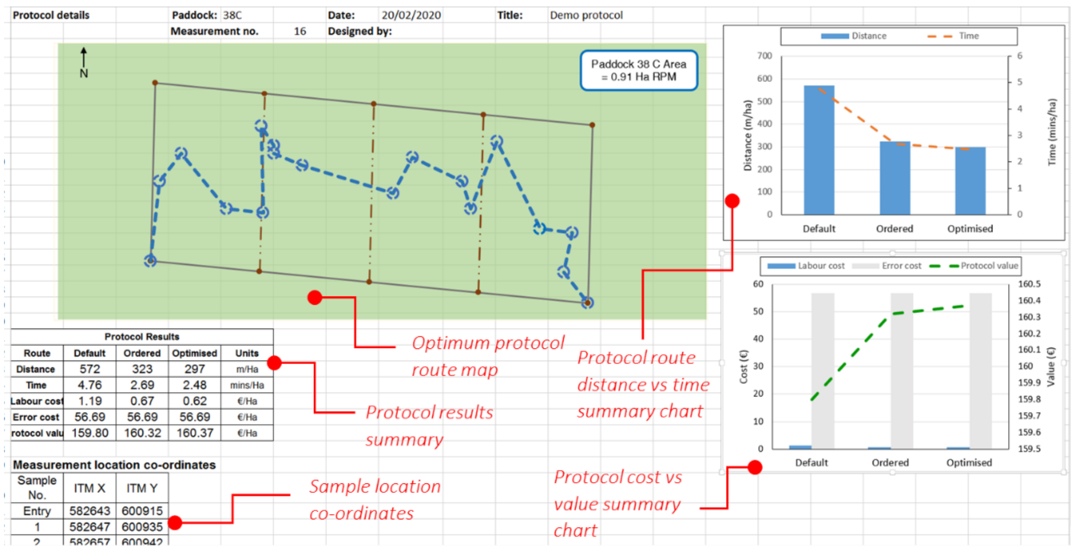

Figure 3.6 GMOT protocol results tab

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