GrassCheck – Improve the robustness of an existing grass growth prediction model, and validation of the model using actual grass growth and meteorological data from sites across Northern Ireland

End of Project Report to AgriSearch

May 2013

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STRUCTURE OF REPORT

This report begins with an Executive Summary which briefly highlights the background to the project, the methods used to undertake the work and the key findings.

The main body of the report highlights the grass growing conditions at each of the monitored sites during each of the two years of the project, and gives a summary of the work involved in the development and validation of the regional accuracy of the grass growth model.

The report finishes with a list of presentations/publications which have been outcomes of the work to date.

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EXECUTIVE SUMMARY

- The project monitored grass growth and quality over two years, namely 2011 and 2012.
- Measurements were taken at six sites across Northern Ireland during these years.
- Sites were at Hillsborough, Greenmount, Portaferry, Fintona, Aghadowey and Tempo.
- Grass growth was estimated from nine plots at each site, with a set of three plots cut each week in a three-week cycle, thus simulating grass growth under a rotational grazing situation.
- The grass growth and quality data collated within this project were released in a weekly 'bulletin' to the farming press and published on the AFBI and RURAL PORTAL websites during the main grazing season (March to October).
- In addition to reporting actual grass growth on a weekly basis, grass growth predictions for one and two weeks ahead were also published. Compared to the average growth of the sites measured each year, these predictions had an accuracy in excess of 76% for both the current week and one week prediction.
- To aid the interpretation of the grass growth data, additional grassland information was added to the weekly bulletin. This information was generated from dairy herds around Northern Ireland and included key grassland management data (grass covers, grass demand, grass growth, grass feed wedge) and animal performance data (milk yields, milk quality, levels of supplementary feeding).
- The highest annual herbage yield during the project was recorded at Greenmount in 2011 (12.8 t DM/ha), while annual herbage yields of 10 t DM/ha or below were recorded at five of the sites in 2012 (Table A).
- The average annual yields recorded across the two years of the project at the Hillsborough, Greenmount, Portaferry, Fintona, Aghadowey and Tempo sites were 10.1, 12.0, 8.9, 10.1, 10.8 and 10.7 t DM/ha, respectively
- The average annual herbage yields recorded during 2011 and 2012 across the sites were 11.2 and 9.6 t DM/ha, respectively.

Table A. Total annual herbage production at each of the sites during the two years of the project

	Total annual herbage production (t DM/ha)		
	2011	2012	Average
Hillsborough	10.5	9.7	10.1
Greenmount	12.8	11.1	12.0
Portaferry	9.0	8.7	8.9
Fintona	11.9	8.2	10.1
Aghadowey	11.5	10.0	10.8
Tempo	11.3	10.0	10.7
Average	**11.2**	**9.6**	**10.4**

- The growth data collected within the project demonstrated the variability of growth between years and also between sites within years. This highlights the need for grassland farmers to have access to local and accurate grass growth information to allow confident and timely grassland management decisions to be made throughout the grazing season.
- Collecting meteorological and growth data across two consecutive years from the six sites provided a robust dataset to validate the ability of the growth model to identify regional variations in grass growth.
- The model was updated in terms of its ability to handle seasonal fertiliser applications, its sensitivity to water excesses/deficits and its ability to identify differences in the drainage capacity of the soil type.
- The grass growth simulations from the model and the actual growth recorded at the sites were compared, and in general there was a good relationship between the growth curves, achieving an r^2 in excess of 0.77 for four of the sites over both years.
- This validation process has highlighted the potential of the model to be utilised at a more regional level in future, and provides an opportunity for multiple growth predictions to be made on a weekly basis.
- Provided accurate and timely meteorological data can be captured on a weekly basis from across Northern Ireland, the model could provide grass growth predictions at a more regional level.

GrassCheck – Grass growth data and weekly output during 2011 and 2012

This project involved the measurement of grass growth and quality throughout 2011 and 2012. Measurements were taken at six sites in these years. At each site nine grass plots were established (1.5 m x 5.0 m), with a series of three plots cut each week during the main grazing season (March to October). Thus each series was cut at three-weekly intervals to simulate grass growth under a 21-day rotational grazing situation. The main data collected during each year will be described in this report.

2011 grass growth and grass quality information

Site location and fertiliser nitrogen input

The six sites included in the project in 2011 were Hillsborough, Greenmount, Portaferry, Fintona, Tempo and Aghadowey, highlighted on the map below (Figure 1). During 2011, total fertiliser nitrogen (N) input was 270 kg/ha, with fertiliser applied to the plots in early spring and at each cut from March to mid September. The application pattern for the full year is given in Appendix 1.

Figure 1 The location of the six sites used within the project in 2011

Grass growth at the sites

Following a very harsh winter, grass growth at most GrassCheck sites was above average by the end of March 2011. While April was a dry month, with only 22 mm of rainfall measured at AFBI Crossnacreevy (less than a third of the long term average), grass growth was actually 40% higher than the seasonal average at most GrassCheck sites. However, soil moisture deficits became apparent by late spring with grass growth falling below the seasonal average at the majority of GrassCheck sites. Figure 2 highlights the weekly grass growth from across the six sites, with the full details provided in Appendix 2.

The challenges of mid-season

A dry mild April was replaced by a cold wet May, with grass growth slowing to approximately 25% below the seasonal average at most sites by the end of May. However, the west of the Province bore the brunt of the poor weather, with over 150 mm (6 inches) of rainfall recorded at Fintona in May, while less than half of this was recorded at Portaferry. Ground conditions in the north and west deteriorated from mid-May onwards, while remaining good in the south and east.

The very different rainfall patterns across Northern Ireland were reflected in differences in grass growth at the Portaferry and Fintona sites in mid-season. While the moist conditions maintained grass growth above the seasonal average in Fintona, an ongoing soil moisture deficit resulted in grass growth remaining below the seasonal average at Portaferry, and this persisted until late September. The persistent nature of the rainfall in the west meant that settled periods of weather of more than 1-2 days were rare during the May to August period. Grazing conditions became difficult at times and some farms experienced grass shortages during July and August as fertiliser application and the harvesting of second cut silage were delayed. Poaching and sward damage were a real issue on many farms.

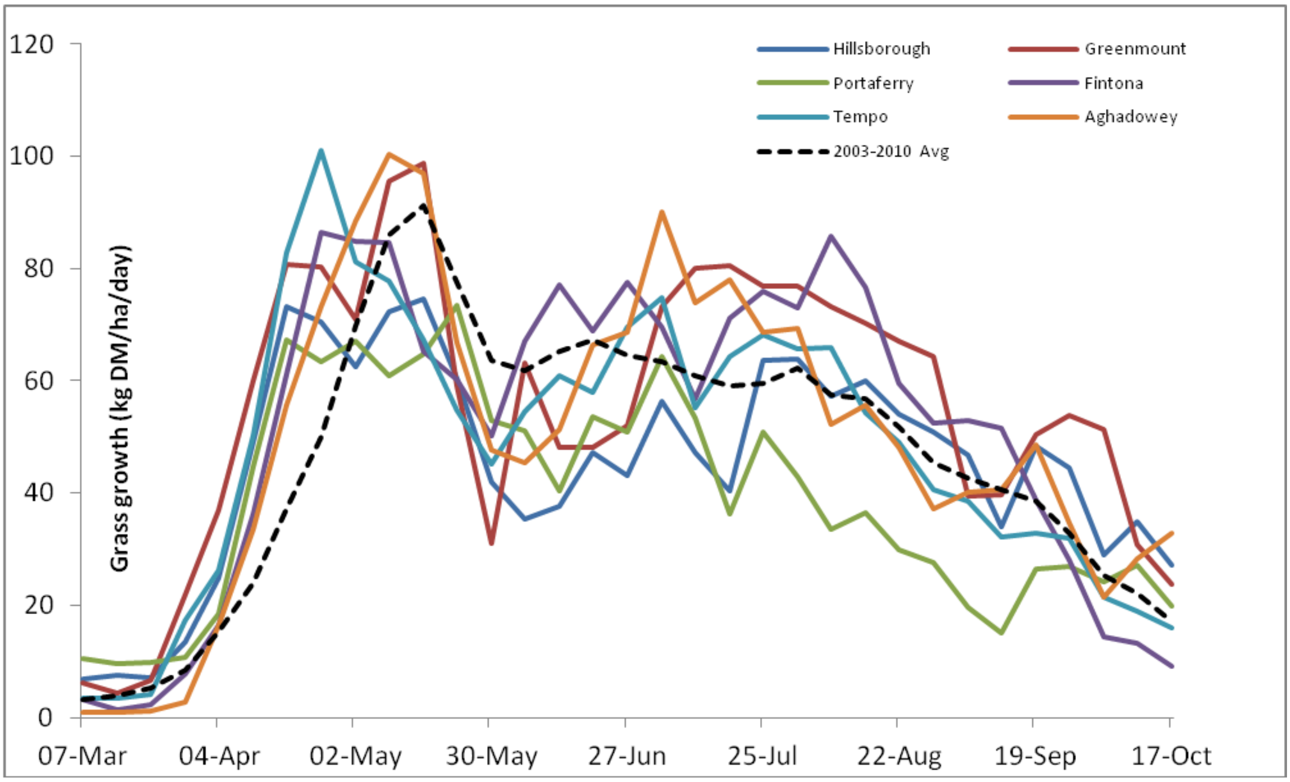
Mild and wet end to the season

The unsettled weather continued through late August/early September; however conditions remained mild and above average growth was recorded at most GrassCheck sites. Although grass was in plentiful supply, the wet weather continued to cause difficult grazing conditions on a number of farms and this had a negative effect on grass utilisation. Many farms had a plentiful supply of grass going into October but deteriorating ground conditions resulted in dairy herds being housed full time. In most cases this grass was subsequently grazed off by dry cows or young stock. Despite the mild temperatures continuing well into late October/early November, rainfall totals remained high, with 145 and 125 mm recorded at Fintona in September and October, respectively, considerably above average for these months.

Total annual herbage production

Average annual herbage production within GrassCheck over the last eight years was 10.7 t DM per ha. In 2011, the average across the six GrassCheck sites was 11.2 t DM per ha, with the highest production recorded at Greenmount (12.8 t DM per ha). Annual herbage production at Fintona (11.9 t DM per ha), Aghadowey (11.5 t DM per ha) and Tempo (11.3 t DM per ha) were above the long term average, while total growth at the drier Hillsborough and Portaferry sites was below average (10.5 t DM per ha and 9.0 t DM per ha, respectively).

Figure 2 Average grass growth measured at each site during 2011 compared to the long term average growth rate (2003 – 2010)

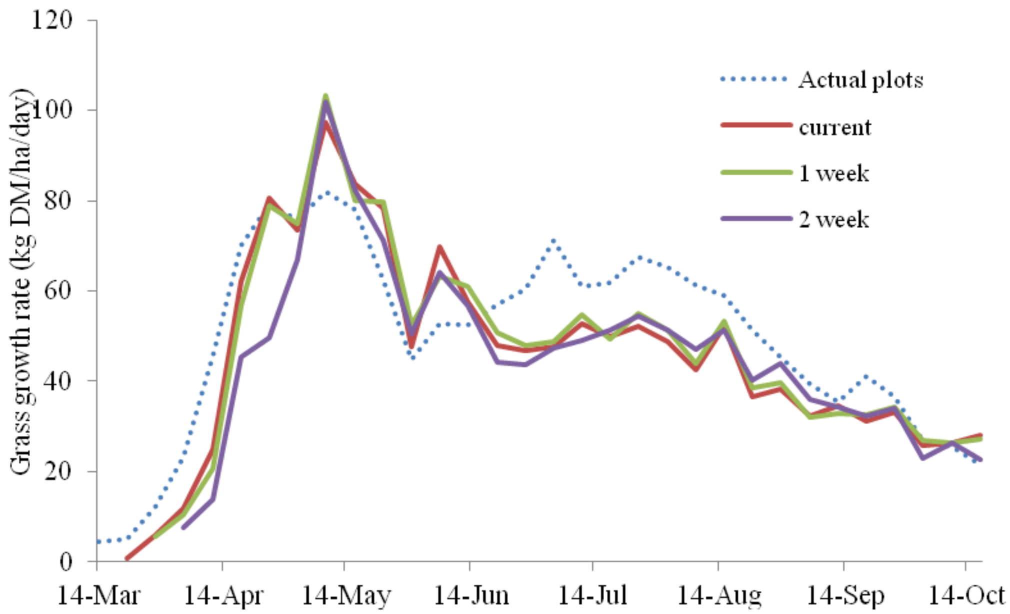


Performance of the grass growth model

Although the main objective of this project was to collate detailed grass growth and meteorological data from six sites across Northern Ireland to be able to validate the grass growth models regional accuracy, as in previous years the model continued to play a key role in the weekly outputs of the project. The model was used on a weekly basis to calculate the grass growth for the current week based on historic weather data collected at Crossnacreevy, and then growth was predicted for the next 14 days based on a weather forecast for Crossncreevy (BT6). These model outputs are shown on Figure 3, compared against the average grass growth measured at the six sites during 2011.

The output of the model for the current week and one and two weeks ahead compared to what was actually measured at the six sites is shown in Figure 3. Across the whole season, the accuracy of the model for the current week was 79%, with an accuracy of 76% achieved for one week ahead and a 63% accuracy achieved for the two week predictions.

Figure 3 The average weekly grass growth measured from the six sites in 2011 compared to the grass growth predicted by the model for the current week and one and two weeks ahead



Although the model is generally very good throughout the early season period, in 2011 the model was consistently underpredicting actual growth throughout March and April. In mid-April, the model was estimating growth 45% below the actual. As a consequence of this underprediction in early season, the model over compensated for growth in mid-May, with predictions being 20% above the actual. The pattern of underprediction then continued through late season, with the predictions being below the actual from mid-June until early October.

Grass quality in 2011

A fresh grass sample from each site each week was analysed by Near Infrared Reflectance Spectroscopy (NIRS), to estimate quality. During 2011 the average metabolisable energy content of the grass harvested at the six sites was 11.9 MJ/kg DM, with the average crude protein being 20.2% DM. Crude protein content followed typical seasonal trends, with high levels recorded in early and late season, and the lowest in mid-season. The average weekly grass quality recorded at the six sites over the duration of the growing season is shown in Appendix 3.

2012 grass growth and quality information

Site location and fertiliser nitrogen input

The six sites included in the project in 2012 were Hillsborough, Greenmount, Portaferry, Fintona, Tempo and Aghadowey. During 2012, total fertiliser nitrogen (N) input was 270 kg/ha, with fertiliser applied to the plots in early spring and at each cut from March to mid September. The application pattern for the full year is given in Appendix 1.

Grass growth at the sites

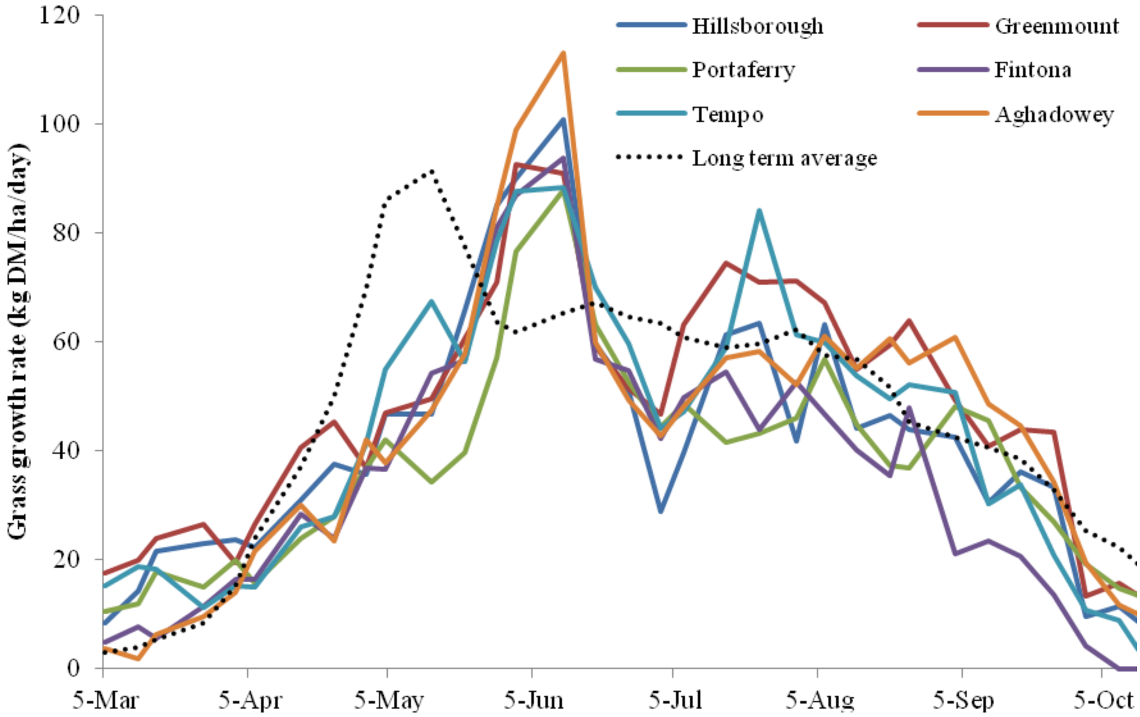
Grass growth

The 2012 growing season actually started off on a high, with mild weather in February and March, resulting in exceptional growth rates during early March. For example, grass growth recorded at Hillsborough and Greenmount during March was over twice the long term seasonal average. However, this period of above average growth was short lived, with growth rates falling below the long term average in early April at all sites (Figure 4 and Appendix 4). With the exception of a three-week period of excellent growth in late May/early June when growth at the majority of sites was in excess of 90 kg DM/ha/day, growth remained below average for most of the remainder of the year. The period of excellent growth in late May represented a later than normal peak to the seasonal growth curve. All sites reached their seasonal peak production during the week beginning 11 June, which is four weeks later than the long term average growth curve. Overall 2012 will be remembered as a very difficult year for growing and managing grass. Weekly grass growth recorded at each site is also presented in Appendix 4.

Total herbage production

The highest yielding GrassCheck site during 2012 was Greenmount with 11.1 t DM/ha harvested, while the lowest yielding site was Fintona with 8.2 t DM/ha harvested. However, the average annual herbage production across the six GrassCheck sites was 9.6 t DM/ha. This is over 1 t DM/ha lower than the long term average annual production, and 1.6 t DM/ha lower than the average annual production achieved at the same sites from the same fertiliser nitrogen input last year. Given the weather conditions and trends in growth already highlighted, this lower growth during 2012 is not surprising. Total annual herbage production was 10.0 t DM/ha at Tempo and Aghadowey, 8.7 t DM/ha at Portaferry and 9.7 t DM/ha at Hillsborough.

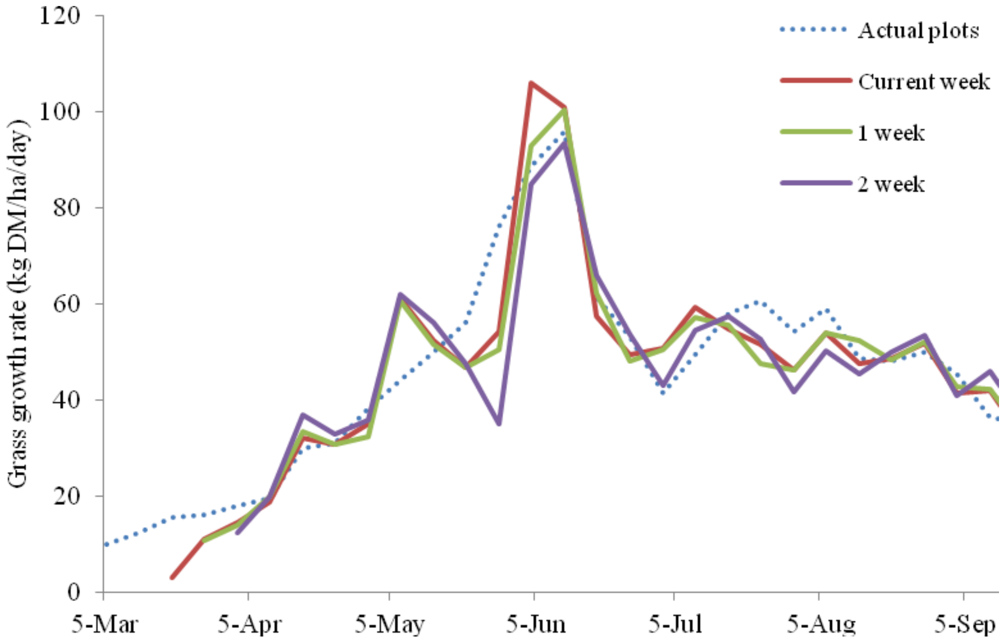
Figure 4 Average grass growth measured at each site during 2012 compared to the long term average growth rate (2003 – 2011)



Performance of the grass growth model

The performance of the grass growth model in 2012 is summarised in Figure 5. Based on actual weather data from AFBI Crossnacreevy, the model's predictions for the average growth of the plots for the current week were 86% accurate, with the one- and two-week predictions being 84 and 69% accurate, respectively. With the exception of the first and last week of May, the model output closely tracked the actual grass growth during April, May and early June 2012. The 2012 season was also unique in terms of the very high and late peak grass growth achieved in mid-June, and the ability of the model to simulate this was encouraging. The model also continued to track along similar trends to the actual growth rates during late season, with a short period of underprediction in late July.

Figure 5 The average weekly grass growth measured from the six sites in 2012 compared to the grass growth predicted by the model for the current week and one and two weeks ahead



Other data collected during the year

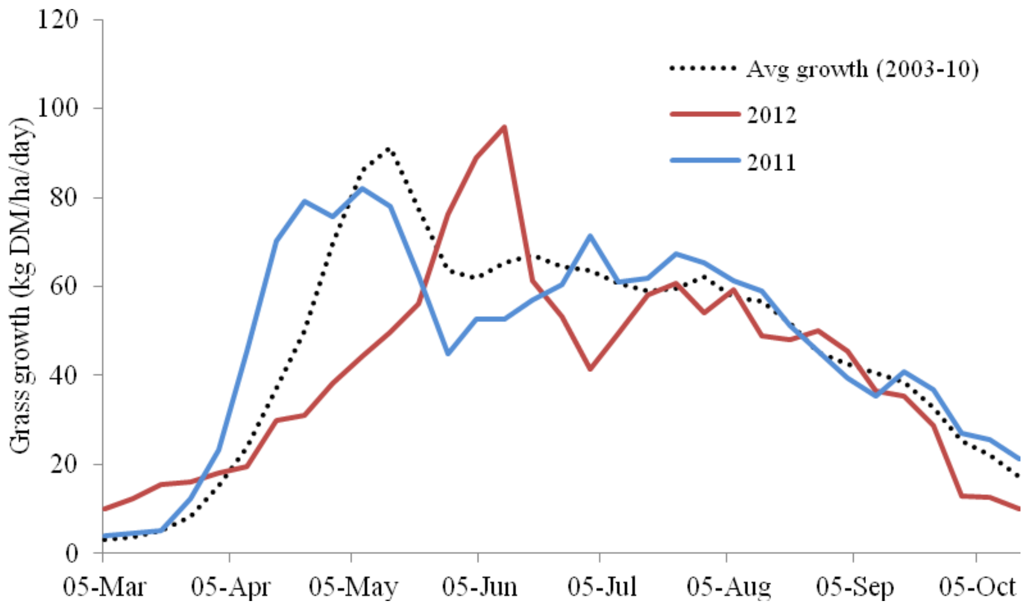
During 2012 the average metabolisable energy content of the grass harvested at the six sites was 11.7 MJ/kg DM, with the average crude protein content being 20.5% DM. The average weekly grass quality recorded at the six sites over the duration of the growing season is shown in Appendix 5.

Overall summary of the two years

Grass growth

This project included two full growing seasons, and grass growth during the season was very different between years, reflected also in a 1.6 t DM/ha difference in the average total annual yield produced by the six sites (11.2 t DM/ha in 2011 to 9.6 t DM/ha in 2012). The average weekly grass growth measured at the six sites is shown on Figure 6, with the long term average grass growth also included for comparison.

Figure 6 The average weekly grass growth from the sites measured in 2011 and 2012 compared to the long term average (2003 – 2010)



The contrast in growing conditions in both years became apparent right from the start of the growing season, with growth being well above average through March in 2012, whilst growth was much closer to average during this period in 2011. However, from early April the growth in 2011 raced well ahead of average, only returning to average levels in early May, whilst in 2012 growth remained well below average throughout April and early/mid May. Growth in early June was also very different between these two years, with growth in 2012 (96 kg DM/ha/day) almost double that recorded in 2011 (53 kg DM/ha/day). By early July however the roles had reversed, with much higher growth being achieved in 2011 (71 kg DM/ha/day) compared to 2012 (42 kg DM/ha/day).

Examining this variability on an individual site basis, the annual variability of grass growth within each site becomes apparent. Figures 7 and 8 highlight grass growth at the Hillsborough and Fintona sites, respectively, over the two years of the project, with the same information for the Greenmount, Portferry, Aghadowey and Tempo sites presented in Appendices 9, 10, 11 and 12 respectively.

Figure 7 The weekly grass growth and the total annual herbage production (t DM/ha) recorded at the Hillsborough site during the two years of the project

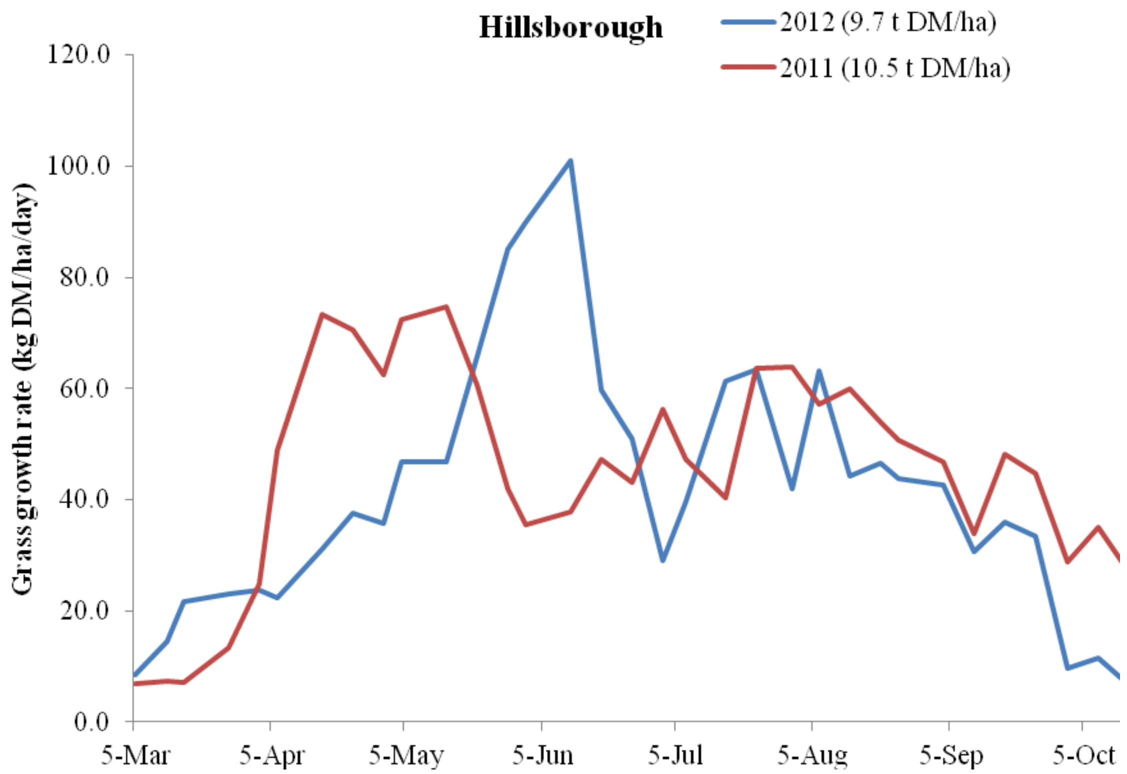
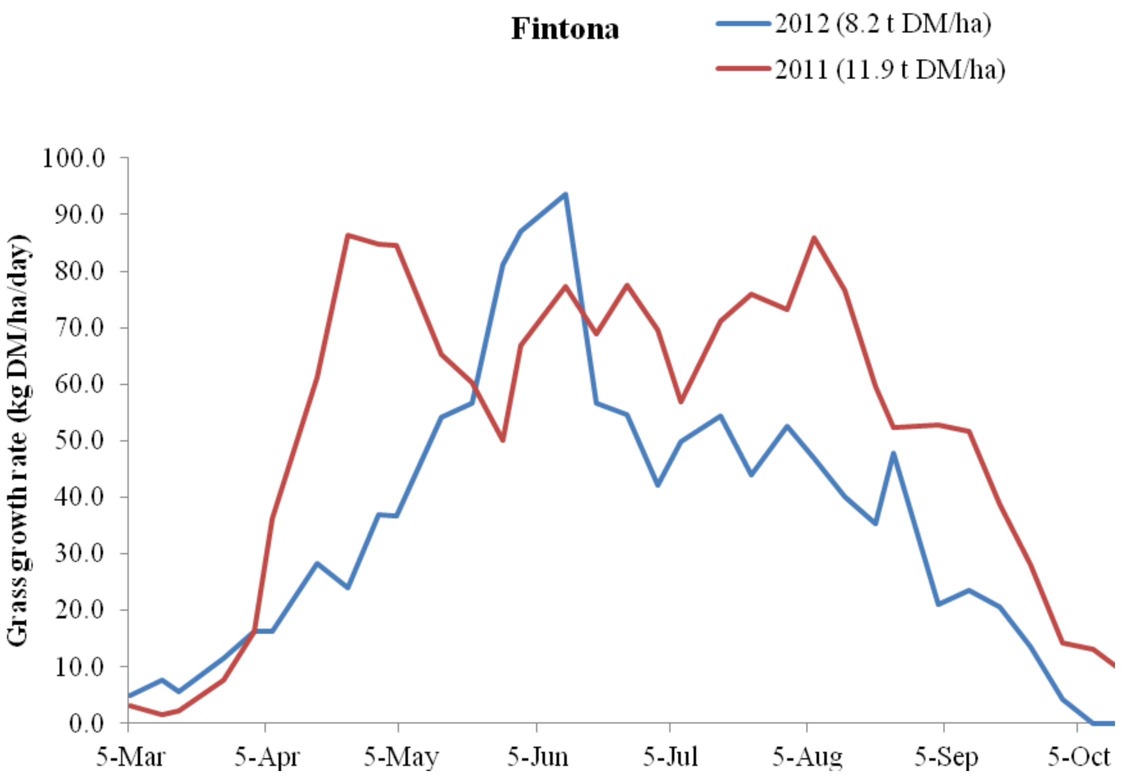


Figure 8 The weekly grass growth and the total annual herbage production (t DM/ha) recorded at the Fintona site during the two years of the project



Additional information within bulletins – Grazing Management Focus

The inclusion of additional grassland and herd performance information in the weekly bulletin was a important development to the project in recent years. This element of the project was aimed at improving the overall interpretation of the growth data presented, with above/below average growth rates from the monitored sites reflected as surpluses or deficits of grass on the grazing platforms on actual dairy herds. Whilst this element was never designed to demonstrate best practise grazing management, some of the data presented in this feature received criticism from the dairy industry. This element of the GrassCheck bulletin will continue to evolve in an attempt to address some of the main concerns raised.

In addition to the extra information, the distribution of the weekly bulletins has also changed, with the bulletins now uploaded weekly to the internet. The weekly bulletins and the periodic press releases are all available on the Rural Portal and AFBI websites. An example of the bulletin as it appeared in the farming press during 2011 and 2012 is given in Appendix 6.

Collection of site specific meteorological and grass growth data over two years for the validation of the grass growth model

Throughout both years of this project, in addition to the weekly measurement of grass growth from the six sites highlighted previously in this report, additional meteorological and soil information were also collected. Tinytag dataloggers were installed at each site, and these dataloggers recorded the daily rainfall, maximum and minimum daily air temperature, the soil temperature and the soil moisture. Soil moisture was also calculated from soil cores (7.5 cm deep) collected weekly from each of the six sites. These soil cores were dried in an oven for 24 to 48 hours to determine the ratio of soil moisture to dry soil. When interpreting these measurements, it has been found that growth is reduced whenever the soil moisture:dry soil ratio drops below approximately 0.40, although this varies depending on soil type.

Meterological data collected in 2011

A complete summary of the meteorological data collected from each site during 2011 is provided in Apendicies 13 - 18. A summary of these data are highlighted in Figures 9, 10, 11 and 12 for a selection of the sites. Figures 9 and 10 highlight the average daily air and soil temperatures at four of the sites over the duration of the growing season in 2011. The information highlights that apart from some brief periods, overall temperatures do not vary widely between the sites.

Figure 9 The average daily air temperature recorded at Fintona, Tempo, Hillsborough and Portaferry during 2011

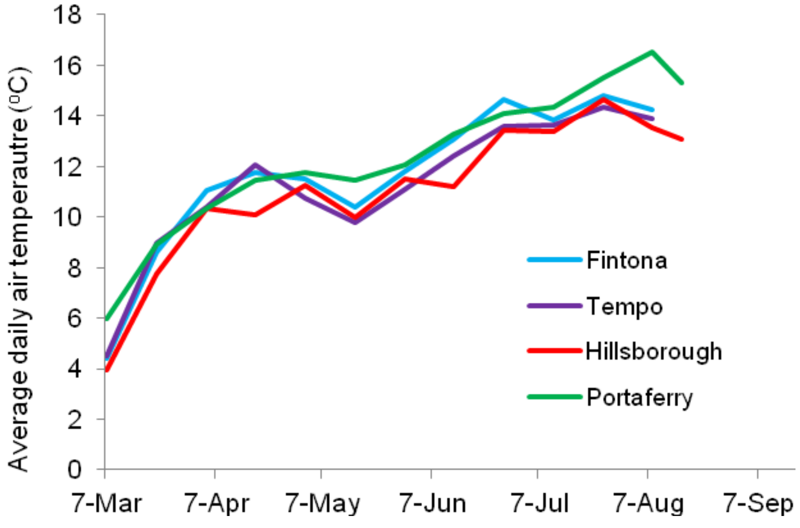
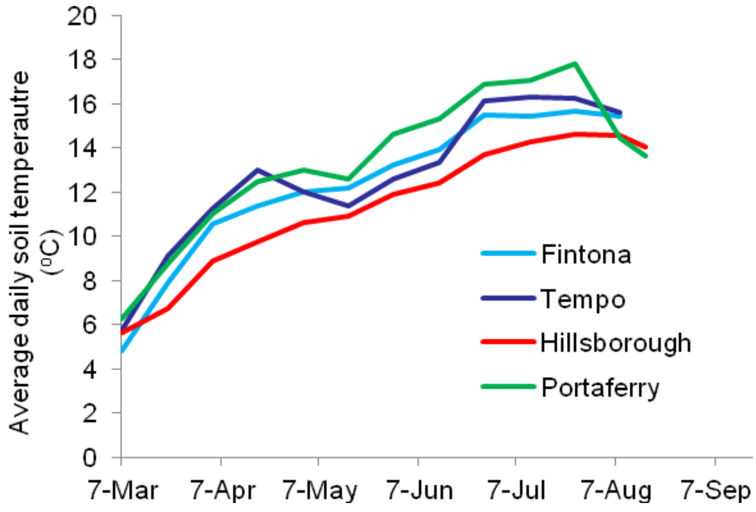


Figure 10 The average daily soil temperature recorded at Fintona, Tempo, Hillsborough and Portaferry during 2011



Figures 11 and 12 highlight the accumulated rainfall and the soil moisture content at a selection of the sites. Despite the similarity in temperatures across the locations, it is clear that there are marked differences in the quantity of rainfall received at each site, and also how this rainfall then affects the soil moisture. It is clear from Figure 11, that Fintona being in the west of the province is receiving much more rainfall than the east of the province (Hillsborough and Portaferry), with accumulated rainfall in early August in Fintona being over twice that of Portaferry. It is also clear that this range in rainfall, coupled with differences in soil type and drainage capacity, results in a wide range in soil moistures, as highlighted in Figure 12 (also shown in Appendix 7). As expected the soils at Hillsborough and Portaferry consistently recorded the lowest contents of moisture, with the heavier soils at Fintona and Aghadowey recording the highest.

Figure 11 The accumulated rainfall recorded at Fintona, Hillsborough and Portaferry during 2011

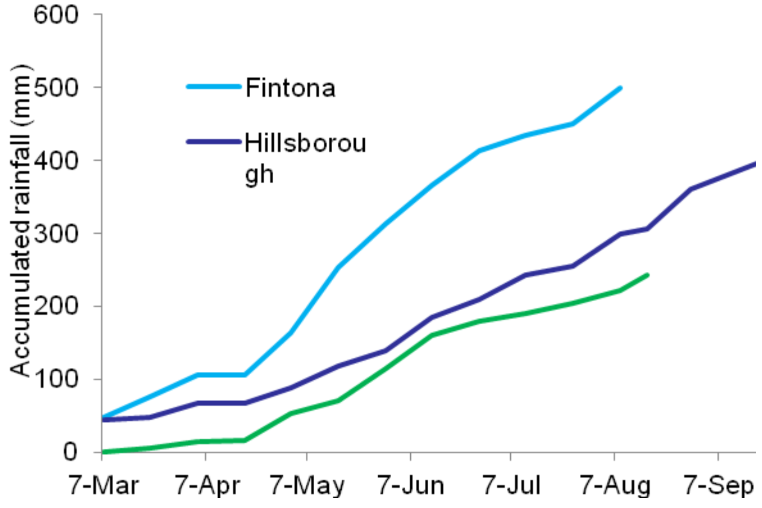
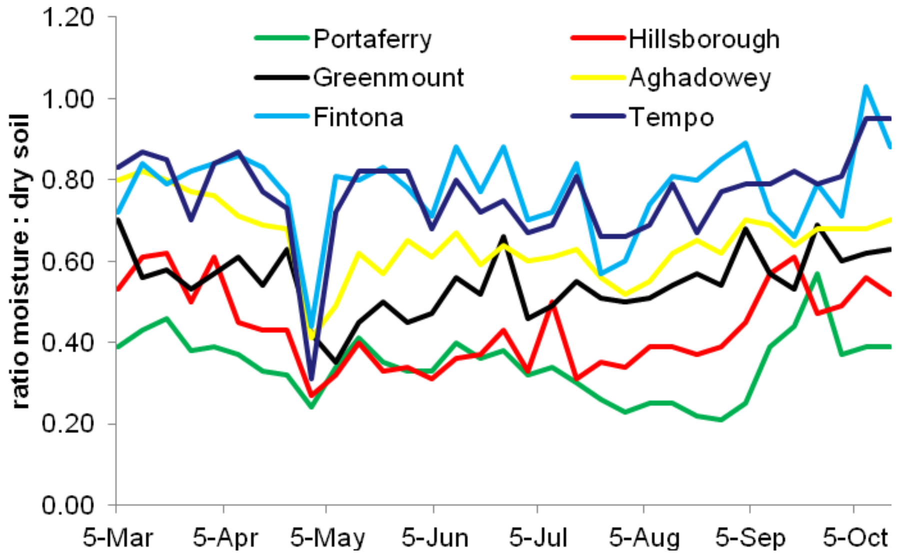


Figure 12 The weekly soil moistures recorded at all six sites during 2011



Meterological data collected in 2012

As in 2011, the same tinytag recorders were used during 2012 and the data collected are highlighted in Appendices 13 - 17. A summary of these data is shown in Figures 13, 14, 15 and 16. Similar to the results in 2011, the air and soil temperatures recorded at the sites did not vary widely (Figures 13 and 14), however the quantity of rainfall and the resulting soil moistures were again the main difference.

Figure 13 The average daily air temperature recorded at Fintona, Tempo, Hillsborough and Aghadowey during 2012

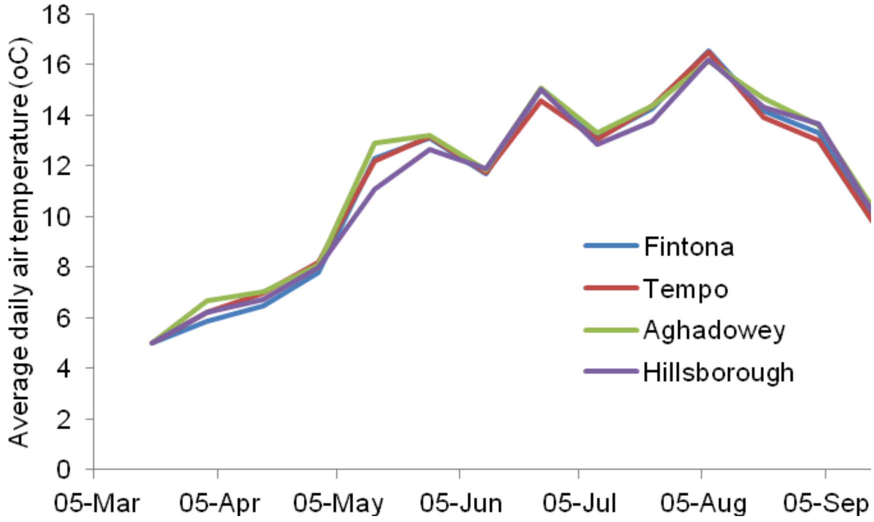


Figure 14 The average daily soil temperature recorded at Fintona, Tempo, Hillsborough and Aghadowey during 2012

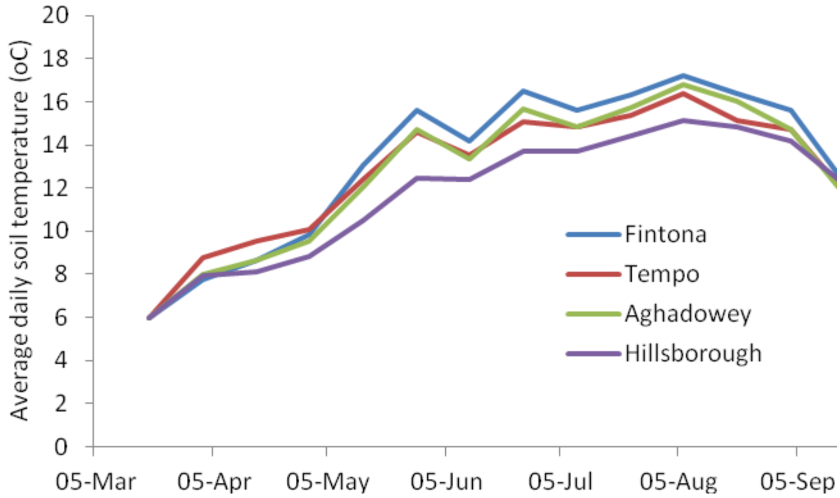


Figure 15 demonstrates that although the extreme rainfall events did occur across a wide area e.g. in excess of 80 mm falling at three of the sites in early June, again the accumulated rainfall totals were different between sites. By early August, the accumulated rainfall at Fintona was again well in excess of Portaferry. Soil moistures were also different between sites. In particular, the heavier soils at Fintona clearly had the highest soil moisture content throughout the majority of the growing season (Figure 16 and Appendix 8).

Figure 15 The total rainfall recorded over a 14-day period throughout the grazing seaon at Fintona, Tempo, Aghadowey and Hillsborough in 2012

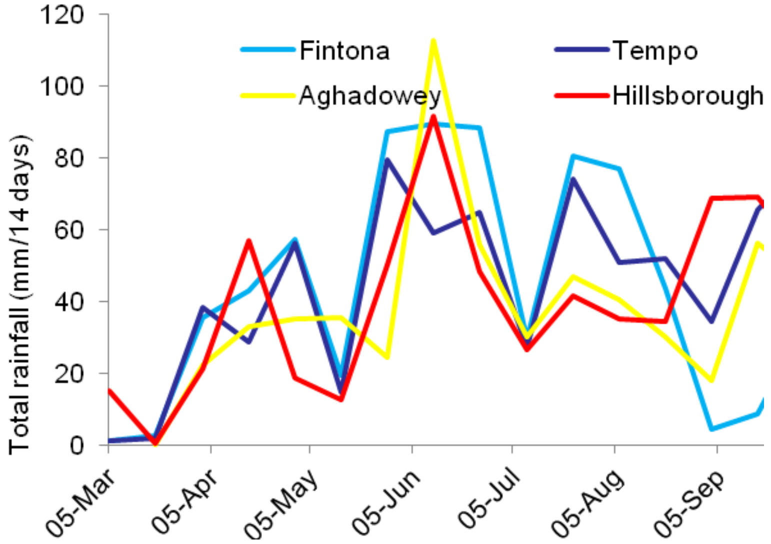
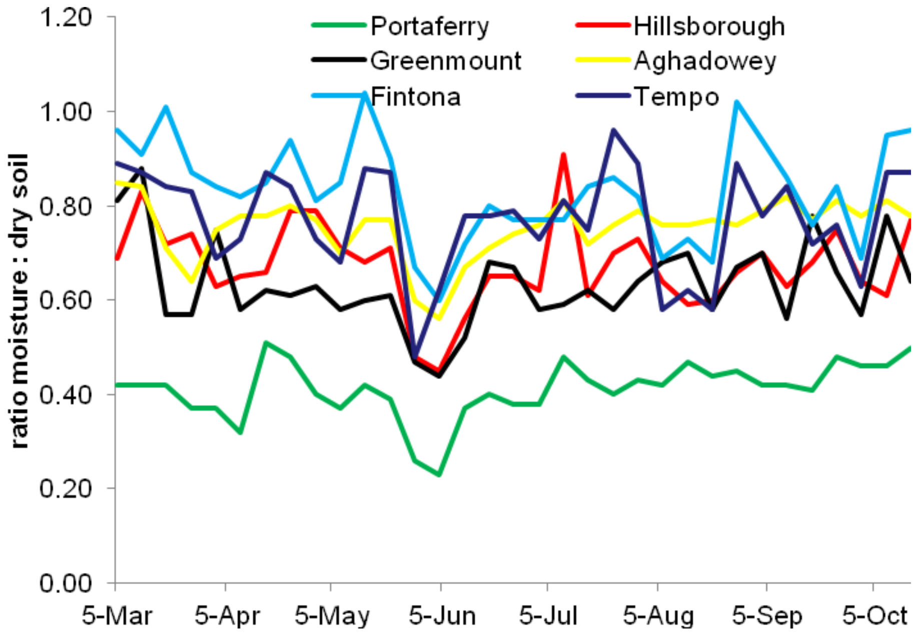


Figure 16 The weekly soil moistures recorded at all six sites during 2012



Comparison of meteorological data collected in 2011 and 2012

The very different grass growth pattern recorded during 2011 and 2012 has already been highlighted, and therefore it would be expected that the meteorological data collected during both years should also reflect these differences. Figures 17 and 18 highlight the air and soil temperature data collected at Hillsborough, Fintona and Tempo over both years, with Figures 19 and 20 highlighting the rainfall and soil moistures at Hillsborough and Fintona over both years. Although air and soil temperatures were similar during mid and late season, the cold April temperatures in 2012 are clearly evident. The higher rainfall and soil moistures are also reflective of the 2012 grazing season.

Figure 17 The average daily air temperature recorded during 2011 and 2012 at Hillsborough, Fintona and Tempo

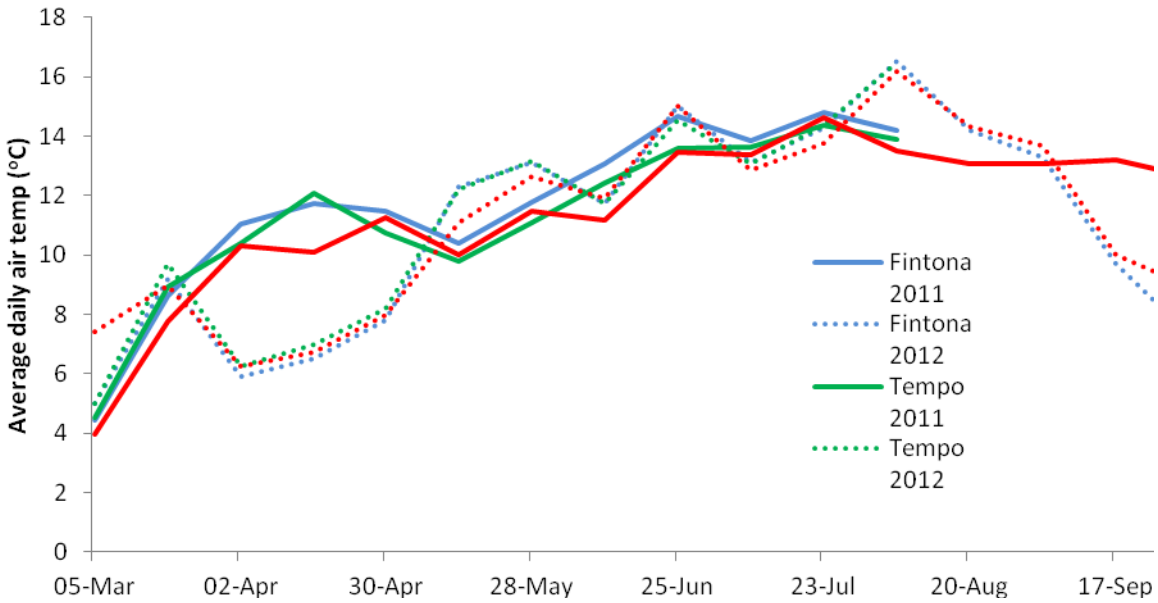


Figure 18 The average daily soil temperature recorded during 2011 and 2012 at Hillsborough, Fintona and Tempo

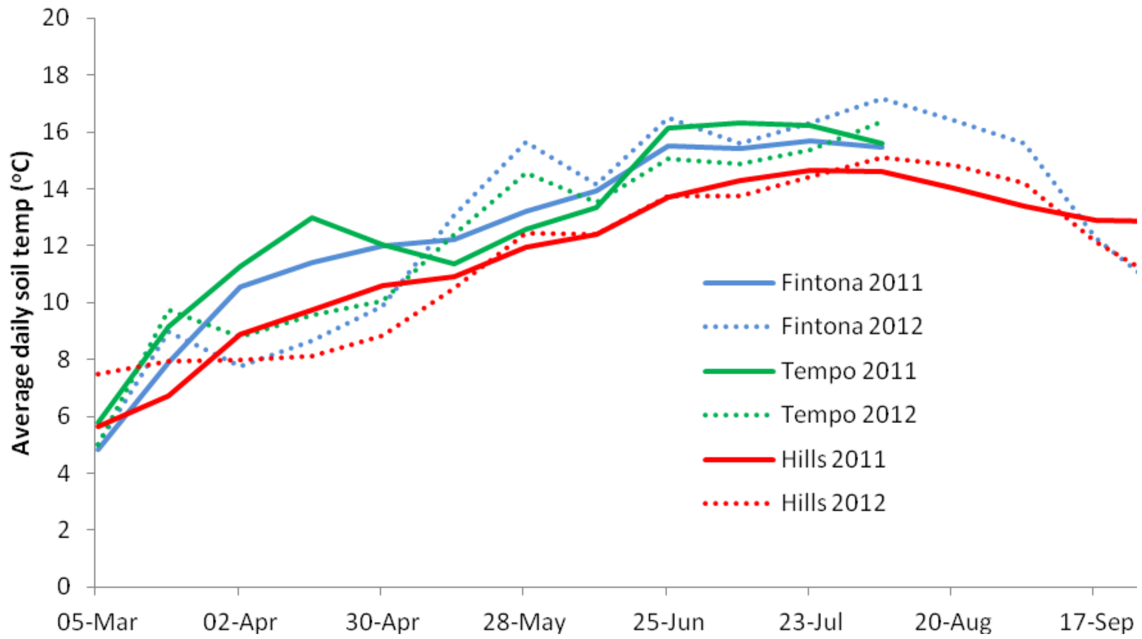


Figure 19 The accumulated rainfall recorded during 2011 and 2012 at Hillsborough and Fintona

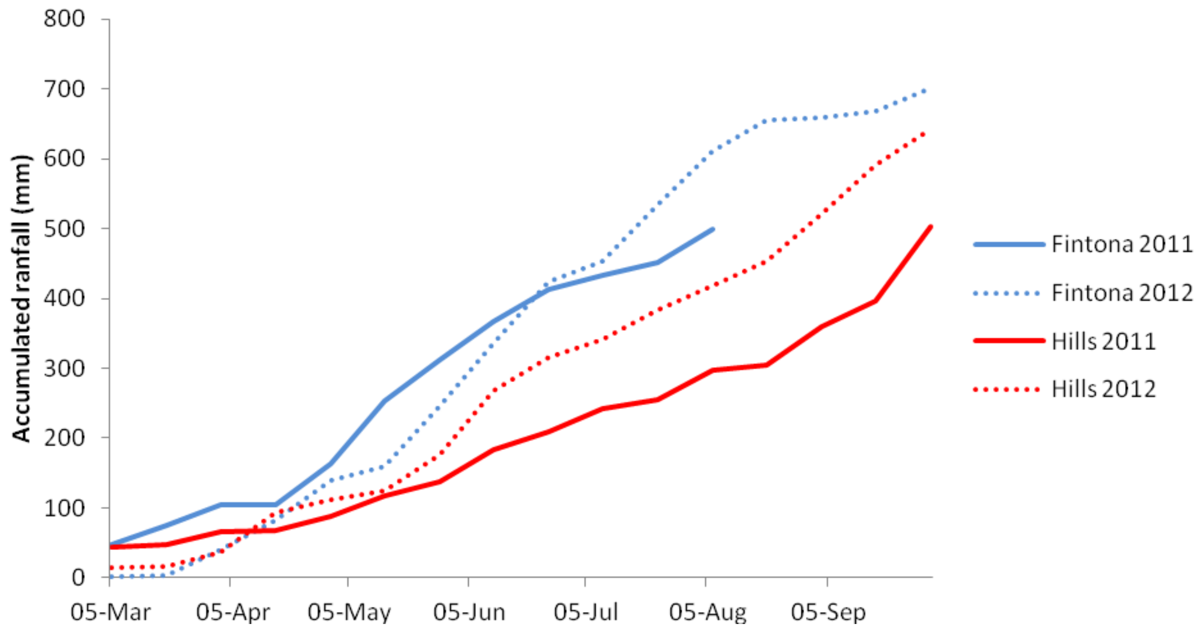
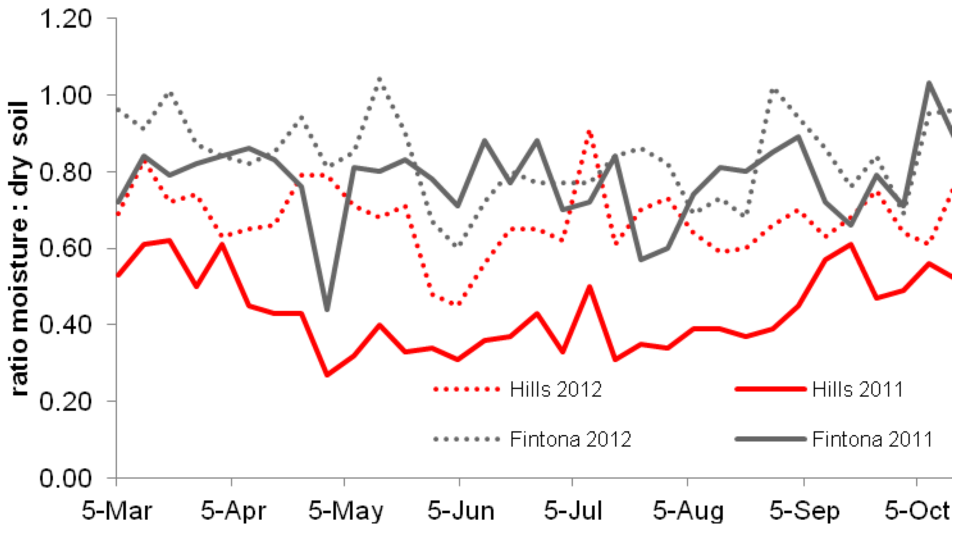


Figure 20 The average weekly soil moistures recorded during 2011 and 2012 at Hillsborough, and Fintona



Grass growth model development.

The original model was developed as part of the EU Project GRAZEMORE (Barrett, Laidlaw and Mayne, 2005, European Journal of Agronomy, 23, 37-56) and tested against data from cut plots from NI, Galacia (N. Spain), W France, South Norway and the Netherlands. It has been used more or less in its original form for grass growth prediction in GrassCheck since its publication.

Over the past few years, a number of limitations of the model have been noted, and it was decided that as well as the development improving the models regional sensitivity, it should also address the current weaknesses of the model. The main focus of the development was on three areas, namely:-

a) Integration of seasonal nitrogen fertiliser applications
b) Sensitivity of model to changes in soil moisture
c) Sensitivity of model to excess soil moisture, including interaction and impact of soil type, soil moisture content, rainfall, evapotranspiration and drainage.

a) Integration of seasonal nitrogen fertiliser applications

Within the original version of the model the integration of the fertiliser applications was based on a single application rate. Although this was sufficient to simulate grass growth over relatively short periods (a few weeks), it was not suitable to replicate the seasonal grass growth curve based on a fertiliser application pattern over the year. The model was therefore modified to allow a seasonal application pattern to be included from the outset, hence the grass growth curve was based on these varying rates and not resulting from an over or under prediction depending on whether a single early or late season fertiliser level was used. This was an important aspect of the development to allow the validation of the grass growth model over the whole season to be completed accurately.

b) Sensitivity of model to changes in soil moisture

The sensitivity of the model to soil moisture is generally acceptable, however during periods of moisture deficit the model can under-predict grass growth after rain is received as the model does not recognise the immediate benefit in growth that can be achieved. A reason for this is the relatively little information that is available within Northern Ireland on grass growth within these conditions, given the infrequency with which periods of severe moisture deficit occur. Nevertheless, this weakness of the model was exposed in 2010, and therefore within this development it was intended to improve this aspect of the model. There is evidence within published literature that during periods of severe moisture deficit, grass growth can recover to almost 80-90% of its potential soon after rainfall, even if the soil remains in moisture deficit. The model works on the principle that although growth remains restricted until the soil moisture deficit is removed, it takes account of growth responding positively to alleviation of deficit. Sensitivity of the model to changes in soil moisture, especially in relation to grass growth immediately after rainfall, will be tested in further developments of the model.

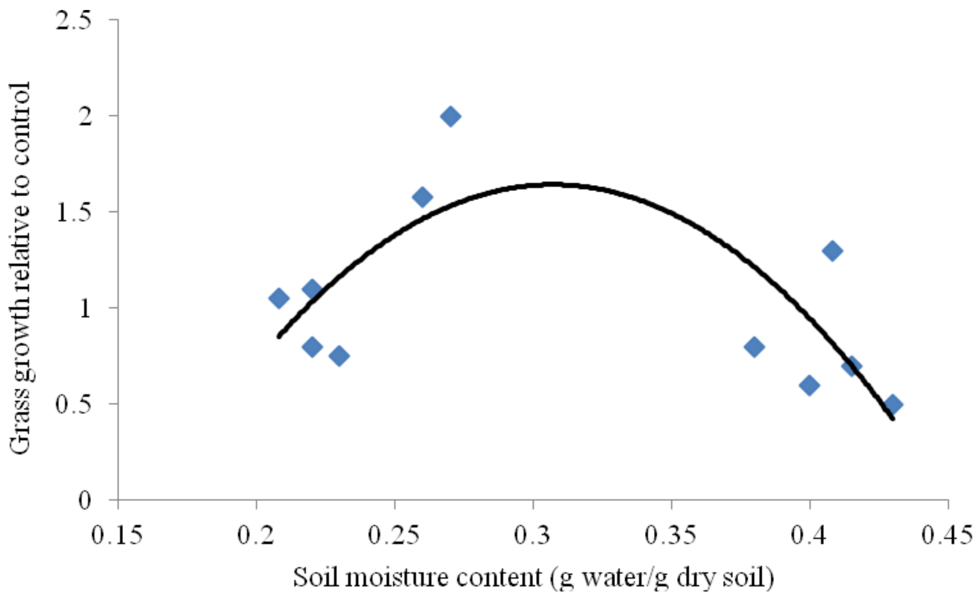
c) Sensitivity of model to excess soil moisture, including interaction and impact of soil type, soil moisture content, rainfall, evapotranspiration and drainage.

Although soil moisture stress was a factor in the original model, a recent development has been the consideration of the impact of excess soil moisture. This is a more common feature of the Northern Ireland climate than soil moisture deficits, and hence the detrimental impact of excess soil moisture should be integrated into the model. The scientific basis of this detrimental impact is clear from Northern Ireland data (Laidlaw 2005, Proceedings of the 20th International Grassland Congress, 551; 2009, Irish Journal of Agricultural and Food Research, 48, 1-20), which highlights the impact of soil moisture content on grass leaf production and photosynthesis (Table 1) and grass growth (Figure 21). Both datasets show that excess soil moisture had a marked effect on dry matter production, and the greater the excess, the greater the impact.

Table 1 Results from a microsward study carried out over four harvesting periods when soil moisture content was maintained at a range of moisture levels as described by proportions of field capacity (Laidlaw, 2005)

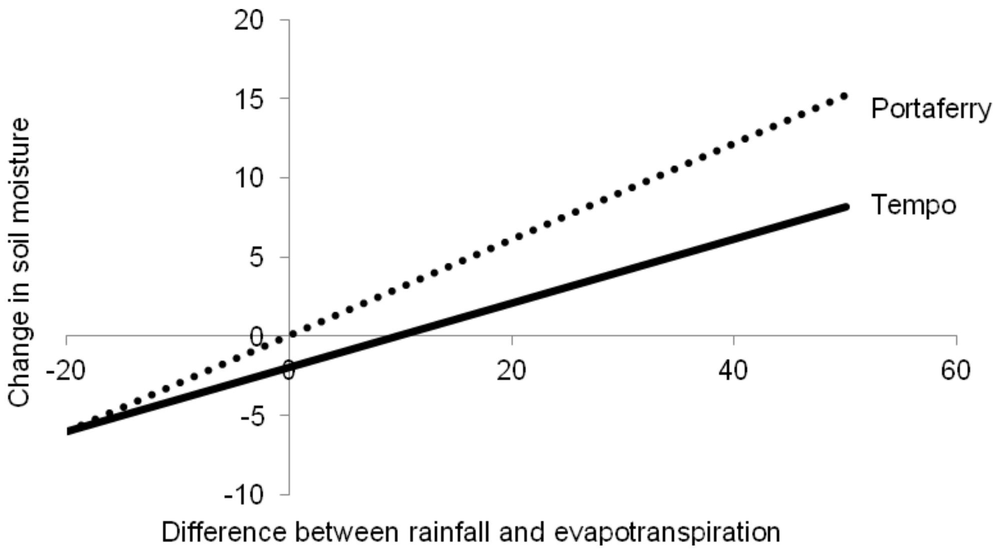
		Week 8		
Soil moisture (Proportion of field capacity)	Leaf extension rate (mm/day)	Leaf area index	Net photosynthesis (g CO_2/m^2/hour)	Net photosynthesis per leaf area index unit
0.50	11.7	4.8	1.4	0.29
0.75	15.8	6.4	1.9	0.30
1.00	14.7	5.5	2.4	0.44
1.25	13.6	4.4	1.6	0.36
Significance	**	***	***	*

Figure 21 Results from a microsward study measuring the impact on grass growth of maintaining soil at a range of moisture levels by varying simulated rainfall rates within a box experiment (Laidlaw, 2009)



To integrate excess soil moisture into the model, the model takes account of the soil type and calculates the approximate soil moisture content. The meteorological data collected allow calculation of the balance between rainfall and evapotranspiration. Relationships between this balance and change in soil moisture have been determined for soils at some of the sites (Figure 22). Soil moisture content is therefore calculated within the model and its impact on grass growth processes as described above are predicted.

Figure 22 Stylised diagram of the relationship between rainfall/evapotranspiration balance and change in soil moisture (litres m^{-2}) for two GrassCheck sites



So in addition to rainfall, the model also takes account of evapotranspiration and drainage at each of the sites. The estimated soil moisture content is included in the calculation of grass leaf extension, photosynthesis and capacity for growth within the model. The ability of the model to track soil moisture content for the various sites was also validated against the soil moisture measurements taken from the plots, and there was good agreement between the predicted soil moisture changes and the actual soil moisture trends observed.

Validation of the changes made to the model

After carrying out the updates and changes to the model, the next stage was to validate these changes, and examine the regional accuracy of the growth simulations. To achieve this a seperate version of the model was established for each of the six sites, and each version was then tailored to suit each site in terms of:-

1. Actual weather data recorded at that site
2. The soil type and drainage capacity of the soil

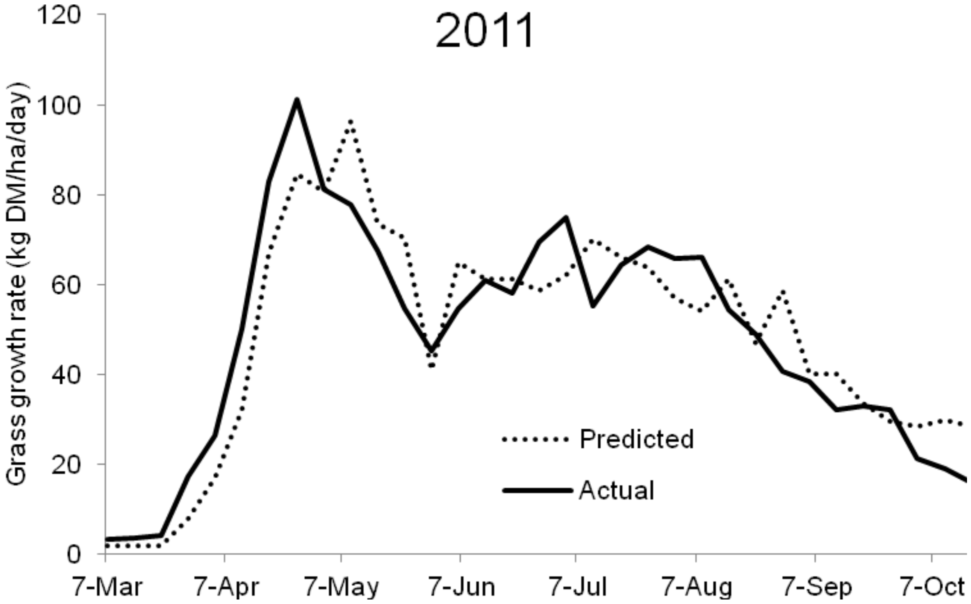
The model was then run for the whole season, and weekly grass growth simulations were produced, and these could then be compared to the growth recorded within the harvested plots. Table 2 provides a summary of how the actual growth rates and the simulated growth rates compared over the two years of the validation. In general there was good agreement between the simulations and the actual growth recorded, achieving an r^2 inexcess of 0.69 for all sites. On average, the r^2 achieved in 2011 was 0.78 and in 2012 was 0.80 across all six sites.

Table 2 Relationship between the actual grass growth measured at the six sites and the growth simulations produced by the grass growth model

	Actual vs simulations (r^2)	
	2011	2012
Hillsborough	0.74	0.69
Greenmount	0.77	0.82
Portaferry	0.69	0.85
Fintona	0.78	0.80
Aghadowey	0.86	0.85
Tempo	0.84	0.78
Average	**0.78**	**0.80**

Figure 23 highlights the weekly growth rates from the model and the actual growth recorded at the Tempo site over both years, with Figure 24 highlighting the same information for the Aghadowey site. It is clear from these graphs that the simulations and the actual growth rates follow a very similar pattern, and these two years provided a robust test for the model given the early burst in growth in 2011 and the late and high peak in 2012. The model also performed resaonably well during the mid and late season periods. The simulations for the other four sites are provided in Appendices 18 – 21.

Figure 23 Comparison of the grass growth simulated by the model and the actual grass growth recorded on the cut plots at Tempo during 2011 and 2012



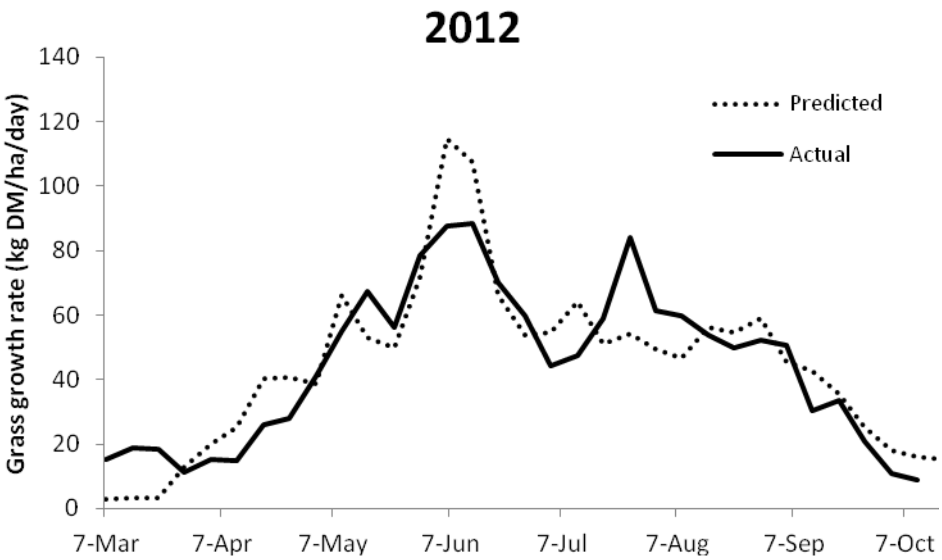
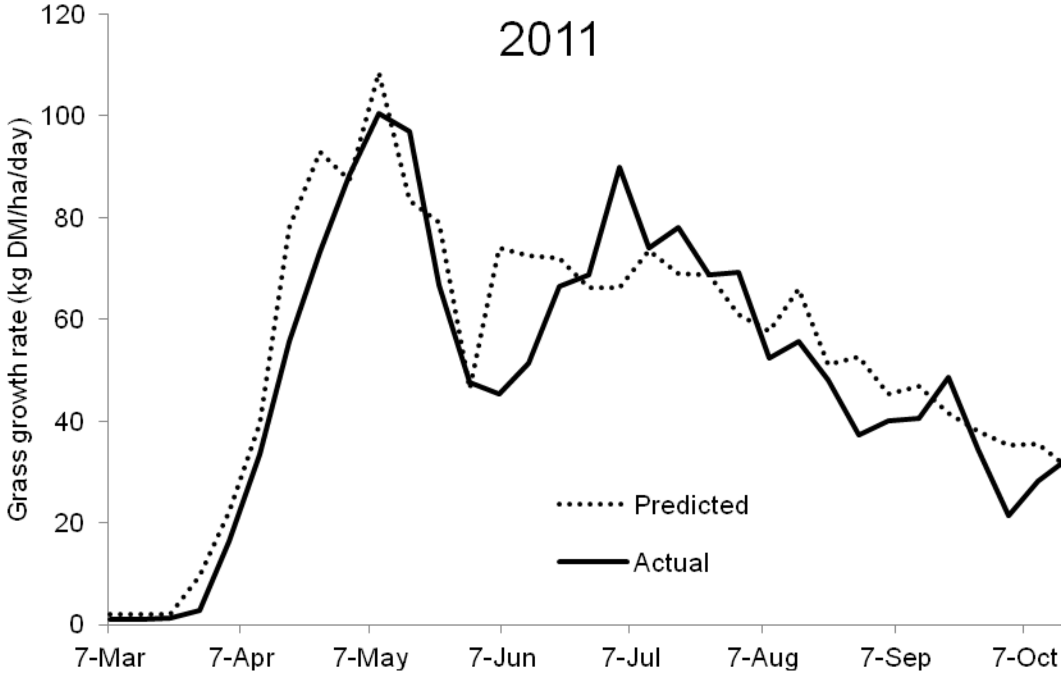


Figure 24 Comparison of the grass growth simulated by the model and the actual grass growth recorded on the cut plots at Aghadowey during 2011 and 2012



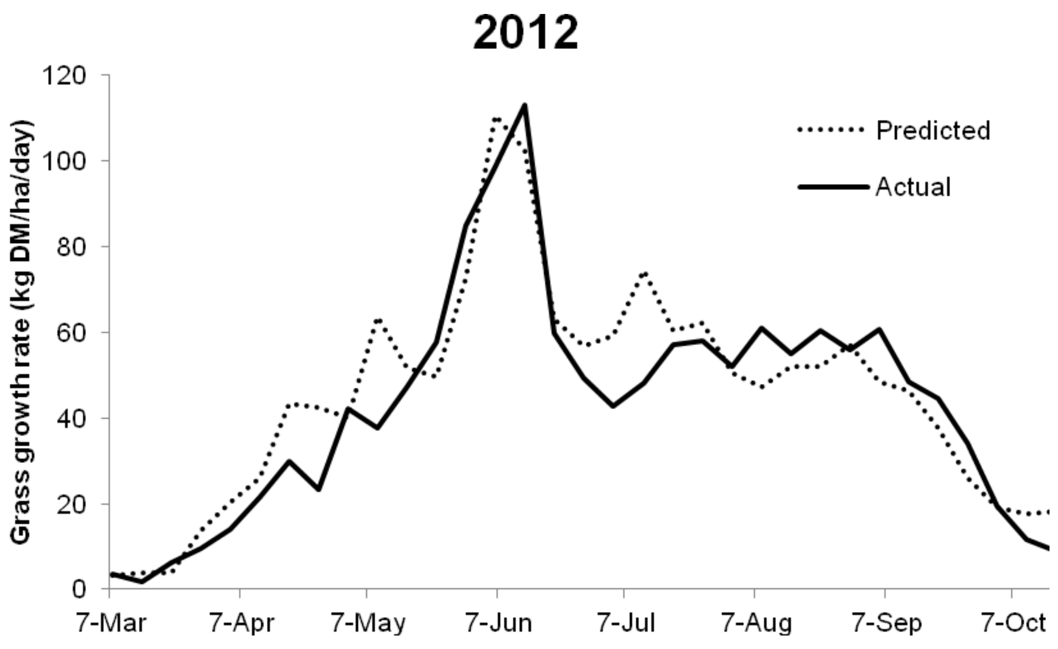
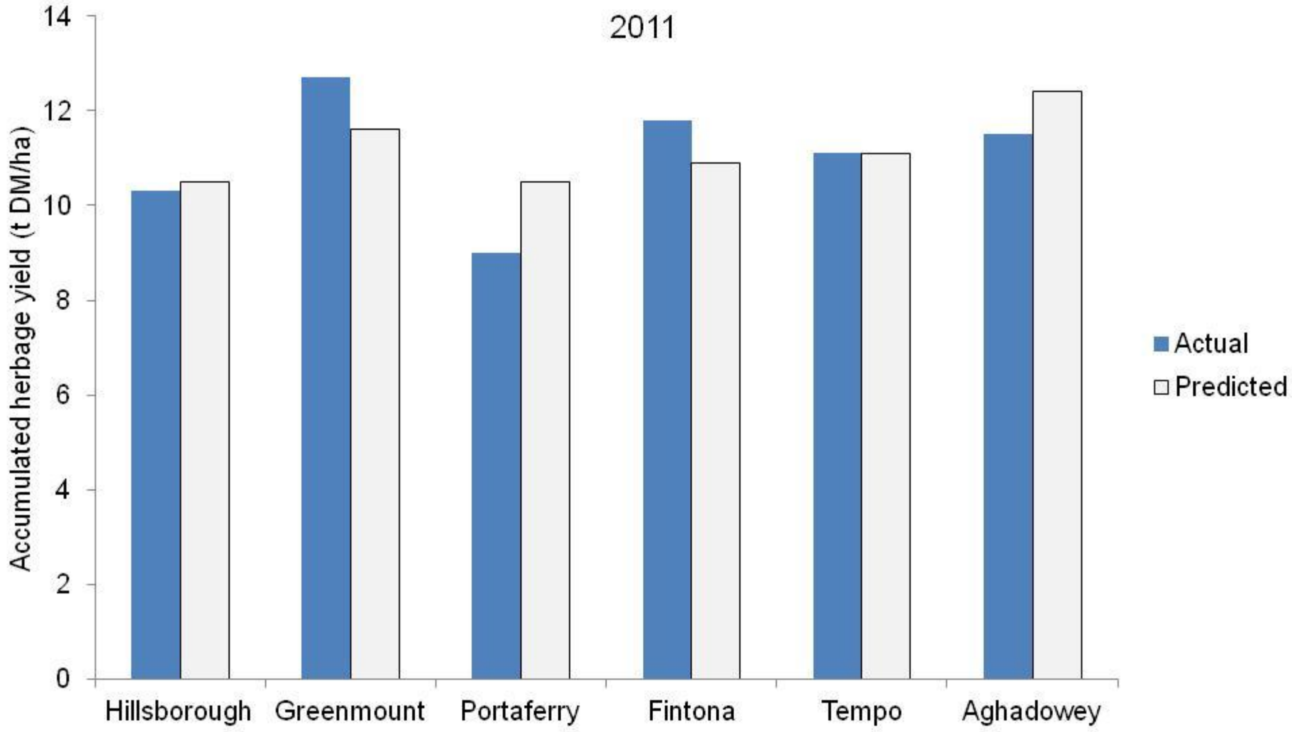


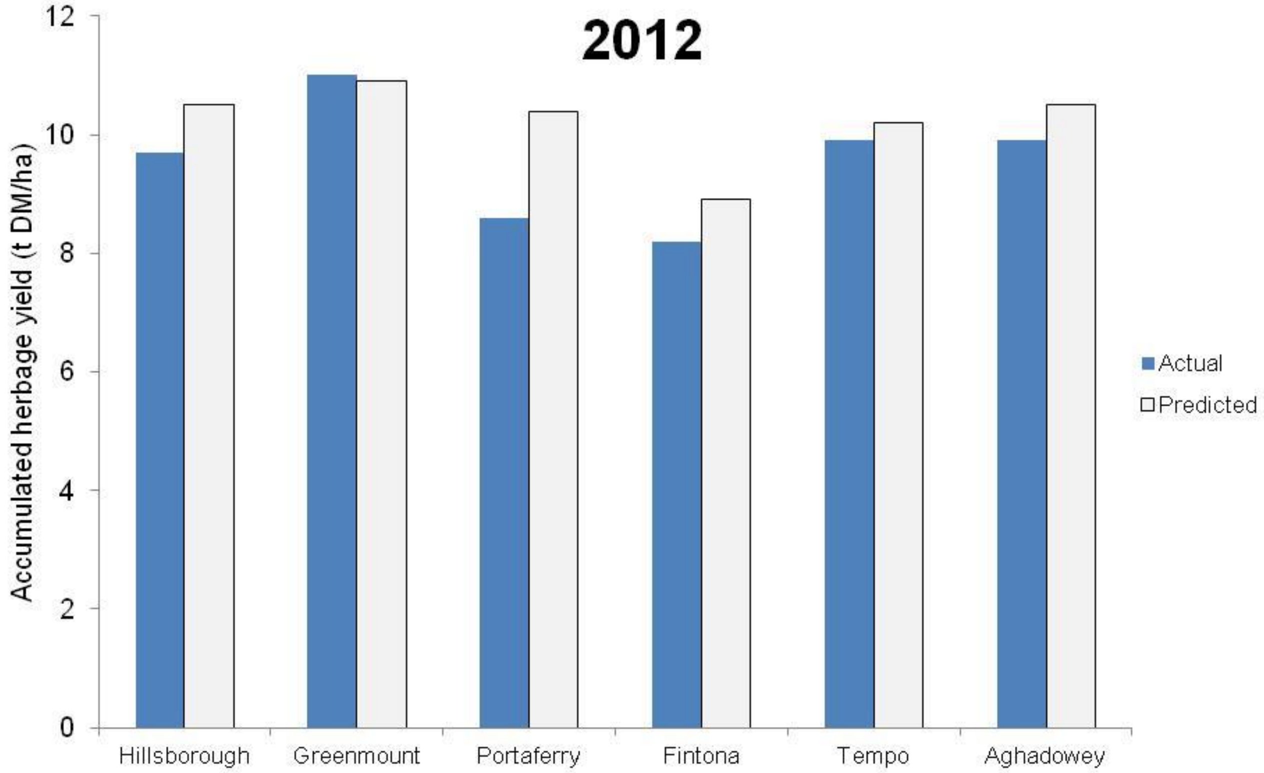
Table 3 Difference between simulated and actual accumulated herbage yield.

	Difference between simulated and actual herbage yields (t DM/ha)	
	2011	2012
Hillsborough	+0.2	+0.8
Greenmount	-1.1	-0.1
Portaferry	+1.5	+1.8
Fintona	-0.9	+0.7
Aghadowey	+0.9	+0.6
Tempo	0.0	+0.3

Although there was good agreement between the simulated and the actual weekly growth rates, any under- or over-estimation of growth by the model will have a potential major impact once this is considered as an annual accumulated yield. The difference between the actual annual yields and the yields achieved by the model are shown in Table 3, and with the exception of Portaferry, the range in accumlated yield is within ±1.1 t DM/ha. These differences are highlighted in Figure 25 also. The data in 2011 show that the model was under-predicting the accumlated yield on two sites, and over-predicting on three. However, in 2012 there was a more distinct trend for the model to over-predict the annual yields, with the model over-predicting the yields achieved on five of the six sites.

Figure 25 Annual accumulated herbage yields based on the actual grass growth harvested from the plots and the growth simulated by the model in 2011 and 2012





Overall summary

Although this two-year project included the familiar weekly outputs in the farming press, the principle reason for collecting the growth and meteorological data was to validate the potential of the grass growth model to identify regional variations in growth. The actual growth data collected clearly highlights that there are regional variations in grass growth, both in terms of total annual yield and also weekly growth rates achieved within each season.

The meteorological data collection was very successful, in terms of the relatively low capital cost of the equipment used, the reliability of that equipment over both years, and the 'added value' the data confer on the model. However, the data transfer from the 'tiny tag' recorders used is not wireless, and also cannot be done remotely. Therefore, this equipment would not provide the required information needed if weekly regional growth simulations were to become a feature of future projects.

Although the two years monitored were consecutive years, with the intention to provide a robust dataset for validation, both years had very extreme grass growth patterns at different times. This is not ideal from a consistency perspective; however it did provide a very good test for the capabilities of the model to simulate these 'extreme' growth patterns. In this regard the model performed admirably, with both the early growth surge in 2011, and the late peak in growth in 2012 simulated successfully.

Given the updates the model has received and also the confidence gained by this successful validation process, it is clear that the model has the potential to be used at a more regional level. However, for the model to be used regionally there is a requirement for accurate and current weather data to be collected locally, in particular air/soil temperatures, soil moisture, rainfall and hours of sunshine. For this information to be collected in a timely fashion on a weekly basis, ultimately these data would need to be transmitted by wireless communication, as the cost of manually downloading data from multiple sites is not feasible given staff availability and cost. There is also a requirement to obtain weather forecast data for individual regions, but this is much more accessible given the range of weather forecasts that are readily available free on the internet.

Therefore, in addition to providing key grass growth information on weekly basis to farmers during two very different and ultimately very challenging grass growing seasons, this project has also delivered an updated version of the grass growth model which has the capability of simulating regional grass growth variations.

KEY PRESENTATIONS

Presentations at conferences

- Dale, A.J. and Laidlaw, A.S. (2013). Validating the ability of a grass growth model to simulate growth from five sites within Northern Ireland. *Proceedings of British Grassland Society and British Society of Animal Science Conference, Profitable and Sustainable Grazing Systems – Moving Forward with Science. Malvern, UK. 26 – 27th February 2013.*

Other publications

- 28 weekly bulletins within the farming press in 2011 (21 March to 26 September).
- 28 weekly bulletins within the farming press in 2012 (19 March to 24 September).
- Getting more from grass in 2011, United News, March 2011
- 2011 – A challenging grazing season! Farming press, December 2011
- 'Spring grass growth reaches record highs as GrassCheck returns,' farming press, March 2012
- 'Making better use of grass in 2012' United News, April 2012
- '2012 - A challenging grazing season comes to an end,' farming press, November 2012
- 'One challenging grazing season comes to an end, the challenges of a new grazing season await', United News, January 2013

Presentations to farmer/industry groups

- The key findings from the study were on display during two winter Dairy Fairs at the Kings Hall.
- During the course of the project, the grass growth data were discussed with a number of farmer and industry groups during visits to both Hillsborough and Greenmount.

APPENDIX 1 Annual fertiliser nitrogen application pattern throughout this project.

Year	2011	2012
	Rate of N (kg N/ha)	
*Before first cut	28 (urea)	28 (urea)
After first cut	28 (urea)	28 (urea)
After second cut	35	35
After third cut	35	35
After fourth cut	35	35
After fifth cut	25	25
After sixth cut	25	25
After seventh cut	25	25
After eighth cut	17	17
After ninth cut	17	17
TOTAL	**270**	**270**

* Applied to all plots in one blanket application

APPENDIX 2 Mean grass growth over the previous three-week period, as measured on a weekly basis at six sites within Northern Ireland during 2011

Date cut	Hillsborough	Greenmount	Portaferry	Fintona	Tempo	Aghadowey
	Average grass growth (kg DM/ha/day)					
07-Mar 11	6.9	6.1	10.4	3.2	3.4	1.0
14-Mar-11	7.4	4.2	9.6	1.4	3.5	1.0
21-Mar-11	7.1	6.7	9.9	2.2	4.2	1.2
28-Mar-11	13.4	21.8	10.8	7.7	17.3	2.8
04-Apr-11	24.9	37.0	18.4	16.4	26.3	16.3
11-Apr-11	49.0	60.0	44.6	36.4	50.2	33.5
18-Apr-11	73.2	80.8	67.3	61.1	82.9	55.8
21-Apr-11	70.5	80.4	63.4	86.4	101.2	73.2
03-May-11	62.6	70.9	67.1	84.9	81.1	88.5
09-May-11	72.4	95.6	60.9	84.6	77.8	100.4
16-May-11	74.7	98.8	64.9	65.2	67.4	96.9
23-May-11	60.5	59.1	73.4	60.3	54.8	66.8
27-May-11	42.0	30.9	52.8	50.1	45.2	47.7
06-Jun-11	35.4	63.1	51.2	67.0	54.6	45.4
13-Jun-11	37.7	48.1	40.3	77.2	60.9	51.4
20-Jun-11	47.1	48.1	53.7	69.0	58.0	66.4
27-Jun-11	43.2	43.2	50.9	77.5	69.5	68.8
04-Jul-11	56.3	73.2	64.2	69.5	74.8	90.0
07-Jul-11	47.2	80.0	53.4	56.9	55.3	74.0
15-Jul-11	40.3	80.5	36.4	71.2	64.4	78.0
25-Jul-11	63.7	77.0	50.9	76.0	68.3	68.8
01-Aug-11	63.9	76.8	42.9	73.1	65.8	69.3
08-Aug-11	57.2	73.3	33.5	85.8	66.0	52.3
15-Aug-11	60.0	70.3	36.6	76.6	54.4	55.8
22-Aug-11	54.0	67.0	29.9	59.5	49.0	48.2
26-Aug-11	50.8	64.4	27.6	52.5	40.7	37.2
05-Sep-11	46.7	39.5	19.6	52.8	38.5	40.1
12-Sep-11	33.9	39.6	15.0	51.6	32.1	40.6
19-Sep-11	48.3	50.5	26.5	38.8	32.9	48.5
26-Sep-11	44.6	53.8	27.0	28.1	32.0	34.6
03-Oct-11	28.9	51.3	24.1	14.3	21.4	21.5
10-Oct-11	35.0	30.7	27.2	13.2	19.0	28.3
17-Oct-11	27.1	23.7	19.9	9.0	16.0	32.8

APPENDIX 3 Average weekly grass quality from the six sites throughout 2011

	Dry matter (%)	Metabolisable energy (MJ/kg DM)	Crude protein (% DM)	Acid detergent fibre (% DM)	Water soluble carbohydrates (% DM)
07-Mar 11	24.1	12.6	23.2	21.6	17.9
14-Mar-11	20.7	12.3	22.9	23.2	17.1
21-Mar-11	22.2	12.9	22.3	20.2	17.8
28-Mar-11	21.5	12.7	23.6	21.0	15.8
04-Apr-11	17.4	12.1	24.1	24.4	13.4
11-Apr-11	17.9	11.9	21.7	25.6	14.1
18-Apr-11	16.1	11.7	22.2	26.8	12.4
21-Apr-11	16.1	11.4	21.2	28.7	11.3
03-May-11	20.5	12.2	17.3	24.3	18.6
09-May-11	18.8	11.8	17.9	26.2	16.6
16-May-11	16.4	11.8	18.6	26.4	15.2
23-May-11	17.4	11.9	18.7	25.8	15.4
27-May-11	17.7	12.2	21.5	23.9	14.2
06-Jun-11	17.3	11.8	18.5	26.2	14.7
13-Jun-11	17.5	11.9	17.4	25.7	15.8
20-Jun-11	19.1	12.0	15.5	25.5	17.7
27-Jun-11	17.9	11.7	16.4	26.5	16.0
04-Jul-11	19.2	11.9	15.7	25.5	18.9
07-Jul-11	17.3	12.0	17.7	25.2	16.9
15-Jul-11	17.0	11.7	17.8	27.1	15.4
25-Jul-11	17.7	11.6	17.0	27.7	16.0
01-Aug-11	17.3	11.4	17.0	28.7	14.9
08-Aug-11	17.5	11.4	19.0	28.6	13.3
15-Aug-11	17.0	11.6	19.0	27.5	13.7
22-Aug-11	18.0	11.6	18.3	27.2	14.4
26-Aug-11	16.9	11.6	20.4	27.3	12.7
05-Sep-11	17.6	11.8	21.2	25.9	13.5
12-Sep-11	16.6	11.8	22.7	26.2	11.6
19-Sep-11	15.0	11.6	21.8	27.2	11.0
26-Sep-11	16.2	11.6	22.1	27.3	12.0
03-Oct-11	15.2	11.6	23.5	27.3	9.0
10-Oct-11	14.1	11.4	23.6	28.6	7.5
17-Oct-11	14.2	11.7	26.1	27.1	7.5

APPENDIX 4 Mean grass growth over the previous three-week period, as measured on a weekly basis at six sites within Northern Ireland during 2012

	Hillsborough	Greenmount	Portaferry	Fintona	Tempo	Aghadowey
Date cut	Average grass growth (kg DM/ha/day)					
05-Mar-12	8.5	17.7	10.6	4.9	15.2	3.7
12-Mar-12	14.4	19.9	12.0	7.7	18.8	1.9
16-Mar-12	21.6	23.9	17.8	5.6	18.3	6.4
26-Mar-12	23.0	26.5	15.1	11.5	11.3	9.6
02-Apr-12	23.7	19.5	20.0	16.3	15.3	14.1
06-Apr-12	22.3	26.5	15.7	16.3	15.0	21.6
16-Apr-12	31.0	40.6	24.0	28.4	26.1	30.0
23-Apr-12	37.6	45.2	28.0	24.0	28.0	23.4
30-Apr-12	35.8	36.9	36.9	37.0	41.2	42.0
04-May-12	46.8	47.0	42.1	36.6	54.9	37.7
14-May-12	46.8	49.4	34.3	54.1	67.5	47.3
21-May-12	65.8	60.5	39.7	56.7	56.3	57.8
28-May-12	85.0	70.9	57.0	81.1	78.5	84.9
01-Jun-12	90.0	92.5	76.6	87.0	87.6	98.9
11-Jun-12	100.9	90.9	87.8	93.7	88.3	113.0
18-Jun-12	59.7	59.2	63.1	56.7	69.9	59.9
25-Jun-12	51.0	51.4	52.6	54.6	59.6	49.2
02-Jul-12	29.0	46.6	44.4	42.2	44.2	42.8
07-Jul-12	39.6	63.1	48.6	49.9	47.3	48.2
16-Jul-12	61.3	74.4	41.5	54.5	59.0	57.1
23-Jul-12	63.4	71.0	43.2	44.0	84.2	58.1
31-Jul-12	41.9	71.3	46.1	52.6	61.3	52.0
06-Aug-12	63.3	67.3	56.9	46.8	59.8	61.0
13-Aug-12	44.3	55.0	44.8	40.1	53.7	55.1
20-Aug-12	46.8	59.4	37.4	35.3	49.6	60.6
24-Aug-12	43.9	63.9	36.9	47.8	52.1	56.1
03-Sep-12	42.6	49.4	48.1	21.0	50.7	60.7
10-Sep-12	30.6	40.9	45.5	23.6	30.2	48.6
17-Sep-12	36.1	43.9	33.4	20.5	33.7	44.5
24-Sep-12	33.4	43.4	27.0	13.6	21.0	34.2
01-Oct-12	9.6	13.4	19.3	4.2	10.9	19.5
08-Oct-12	11.5	15.8	14.8	*	8.9	11.8
15-Oct-12	6.7	12.0	12.7	*	*	9.0

* Plots not cut due to very wet weather and poor ground conditions

APPENDIX 5 Average weekly grass quality from the six sites throughout 2012

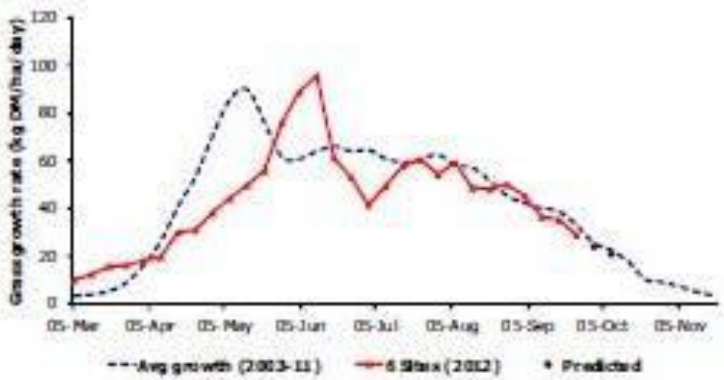
	Dry matter (%)	Metabolisable energy (MJ/kg DM)	Crude protein (% DM)	Acid detergent fibre (% DM)	Water soluble carbohydrates (% DM)
05-Mar-12	17.5	12.2	26.5	23.9	12.0
12-Mar-12	15.4	11.8	27.5	26.0	9.2
16-Mar-12	15.5	11.7	25.3	26.5	10.0
26-Mar-12	17.5	11.8	25.1	26.5	11.5
02-Apr-12	16.3	11.7	23.2	27.2	12.1
06-Apr-12	18.9	11.8	21.7	26.3	14.8
16-Apr-12	21.8	12.4	19.7	22.8	18.4
23-Apr-12	17.1	11.6	22.5	27.3	12.6
30-Apr-12	20.8	12.0	18.1	25.4	17.6
04-May-12	16.8	11.7	22.0	26.6	14.5
14-May-12	18.4	12.0	19.7	25.3	17.2
21-May-12	18.9	11.8	19.7	26.1	16.2
28-May-12	18.2	11.2	18.6	29.6	13.7
01-Jun-12	16.1	11.2	19.5	29.8	11.6
11-Jun-12	16.0	11.0	18.9	30.5	12.5
18-Jun-12	16.8	11.4	19.1	28.6	13.5
25-Jun-12	16.7	11.4	17.8	28.3	14.3
02-Jul-12	14.6	11.5	19.3	27.7	12.2
07-Jul-12	14.3	11.5	18.7	27.9	11.9
16-Jul-12	17.4	11.5	15.8	27.9	16.9
23-Jul-12	15.0	11.6	17.9	27.6	13.4
31-Jul-12	17.9	11.8	16.4	26.1	17.1
06-Aug-12	17.0	11.8	16.6	26.2	15.2
13-Aug-12	15.5	11.5	18.2	27.7	12.8
20-Aug-12	16.6	11.3	19.0	29.0	11.4
24-Aug-12	15.8	11.5	19.9	27.8	11.1
03-Sep-12	16.8	11.7	18.6	27.0	13.7
10-Sep-12	14.4	11.6	21.1	27.1	10.3
17-Sep-12	17.1	12.1	20.1	24.7	13.6
24-Sep-12	15.5	11.9	21.8	25.9	12.5
01-Oct-12	18.1	12.2	22.4	23.7	13.5
08-Oct-12	18.9	12.3	21.0	23.6	15.7
15-Oct-12	16.6	12.4	24.0	22.8	13.2

APPENDIX 6. An example of the weekly bulletins released to the farming press during 2011 and 2012.

GrassCheck

Week beginning 24 September 2012

Grass Growth and Quality



3-week Grass Growth (kg DM/ha/day)*		
Current	24 Sept	29
Predicted	1 Oct	24
	8 Oct	21

* 270 kg N/ha/year applied

Grass Quality	
Dry matter (%)	15
ME (MJ/kg DM)	11.9
Crude protein (%)	22
Sugars (% DM)	13

- Grass growth remains below the seasonal average at half the sites and exceptionally wet weather this week has seen ground conditions deteriorate rapidly once again.
- Options to keep cows at grass include restricting grazing to a few hours after each milking, but on heavier soils grazing with young stock may be the best option.
- Keep grazing the fields in rotation and do not regraze them as there may well be a better opportunity for utilising grazed grass in spring 2013.
- This is the final bulletin of the season.

Grazing Management Focus

Alan Coalter runs a herd of 60 Holstein Friesian cows on his farm near Ballinamallard in Co. Fermanagh. The cows calve mainly from September to April. Alan's system of milk production is based on maximising milk from grazed grass and big bale silage. The herd has an average milk yield of 5,511 litres from a concentrate usage of 806 kgs per cow. Milk from Forage is currently 3,719 litres per cow.

Grass supply

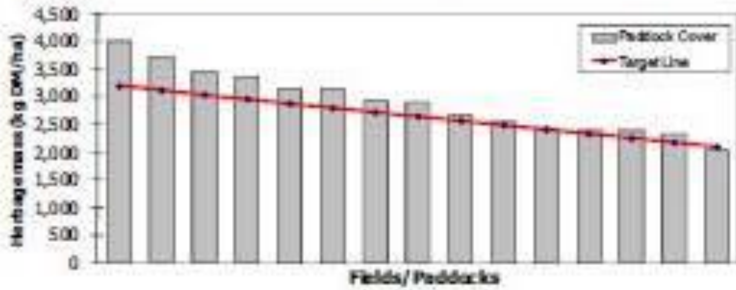
Average farm cover	2,900 kg DM/ha
Pre-grazing cover	3,950 kg DM/ha
7-day grass growth	38 kg DM/ha/day (based on farm cover)
Herd grass demand	36 kg DM/ha/day

Cow performance

Milk yield and quality	16.7 litres/cow/day, 4.73% BF, 3.47% PR
Milk from forage	10.0 litres/cow/day
Concentrate feed level	3.0 kg/cow/day

Management issues

Ground conditions are wet and grazing is difficult. Dry cows are housed full time. At present the milking cows are being grazed during the day and for 2-3 hours after the evening milking and housed overnight. This will be the last grazing rotation and fields are being grazed flexibly to allow for ground conditions as well as grass cover. Fields targeted for early turnout next spring will be grazed next in the rotation if ground conditions are suitable. Fields not tightly grazed by the cows will be grazed again with young light stock.



The target line reflects a pre-grazing grass cover of 3,200 kg DM/ha and a post-grazing grass cover of 2,100 kg DM. This is the quantity of grass required for a stocking rate of 2.4 cows/ha and a rotation of 30 days, with cows eating 15 kg grass DM/day.

afbi AgriSearch Farmer Funded Research cafre

Information is also available on DARD Rural Portal at http://www.ruralni.gov.uk/grasscheck

GrassCheck is a joint project conducted by AFBI, Hillsborough and Greenmount Campus, CAFRE, and is part-funded through producers' levy.

APPENDIX 7 Weekly soil moisture content (ratio moisture to dry) at each of the six sites throughout 2011

	Portaferry	Hillsborough	Greenmount	Aghadowey	Fintona	Tempo
07/03/2011	0.39	0.53	0.70	0.80	0.72	0.83
14/03/2011	0.43	0.61	0.56	0.82	0.84	0.87
21/03/2011	0.46	0.62	0.58	0.80	0.79	0.85
28/03/2011	0.38	0.50	0.53	0.77	0.82	0.70
04/04/2011	0.39	0.61	0.57	0.76	0.84	0.84
11/04/2011	0.37	0.45	0.61	0.71	0.86	0.87
18/04/2011	0.33	0.43	0.54	0.69	0.83	0.77
25/04/2011	0.32	0.43	0.63	0.68	0.76	0.73
02/05/2011	0.24	0.27	0.42	0.41	0.44	0.31
09/05/2011	0.34	0.32	0.35	0.49	0.81	0.72
16/05/2011	0.41	0.40	0.45	0.62	0.80	0.82
23/05/2011	0.35	0.33	0.50	0.57	0.83	0.82
30/05/2011	0.33	0.34	0.45	0.65	0.78	0.82
06/06/2011	0.33	0.31	0.47	0.61	0.71	0.68
13/06/2011	0.40	0.36	0.56	0.67	0.88	0.80
20/06/2011	0.36	0.37	0.52	0.59	0.77	0.72
27/06/2011	0.38	0.43	0.66	0.64	0.88	0.75
04/07/2011	0.32	0.33	0.46	0.60	0.70	0.67
11/07/2011	0.34	0.50	0.49	0.61	0.72	0.69
18/07/2011	0.30	0.31	0.55	0.63	0.84	0.81
25/07/2011	0.26	0.35	0.51	0.56	0.57	0.66
01/08/2011	0.23	0.34	0.50	0.52	0.60	0.66
08/08/2011	0.25	0.39	0.51	0.55	0.74	0.69
15/08/2011	0.25	0.39	0.54	0.62	0.81	0.79
22/08/2011	0.22	0.37	0.57	0.65	0.80	0.67
29/08/2011	0.21	0.39	0.54	0.62	0.85	0.77
05/09/2011	0.25	0.45	0.68	0.70	0.89	0.79
12/09/2011	0.39	0.57	0.57	0.69	0.72	0.79
19/09/2011	0.44	0.61	0.53	0.64	0.66	0.82
26/09/2011	0.57	0.47	0.69	0.68	0.79	0.79
03/10/2011	0.37	0.49	0.60	0.68	0.71	0.81
10/10/2011	0.39	0.56	0.62	0.68	1.03	0.95
17/10/2011	0.39	0.52	0.63	0.70	0.88	0.95

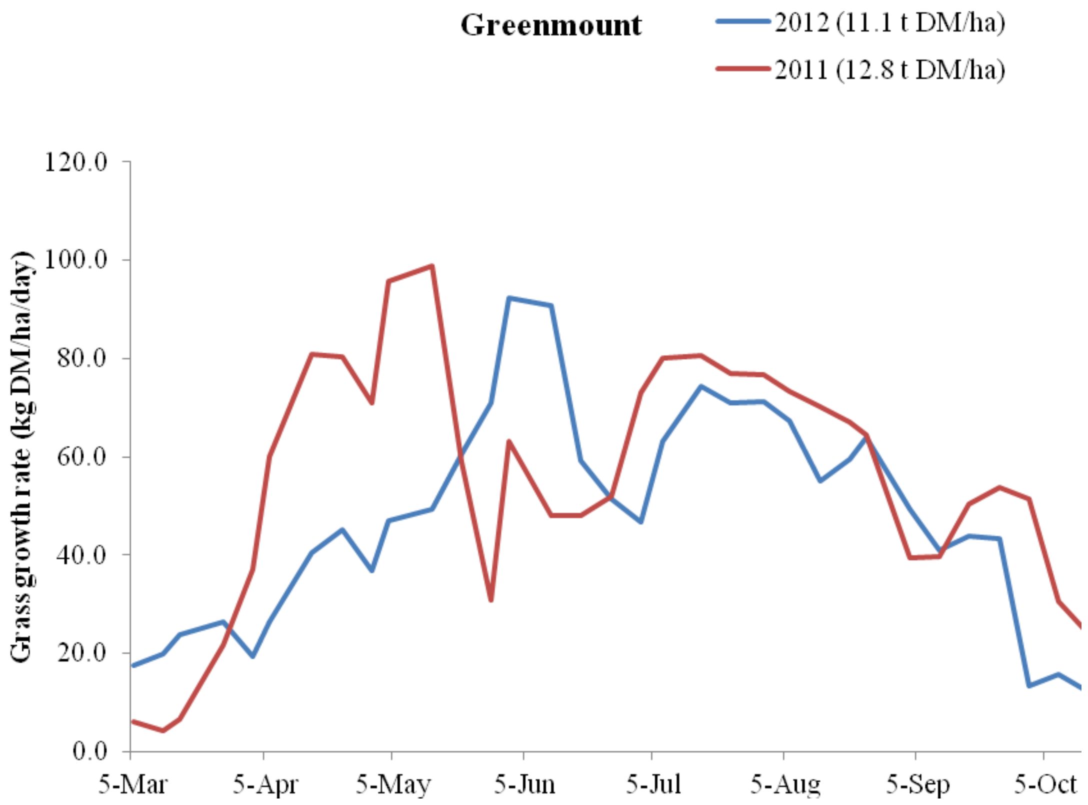
NB. At a soil moisture:dry soil ratio below 0.40, growth rates are likely to be reduced

APPENDIX 8 Weekly soil moisture content (ratio moisture to dry) at each of the six sites throughout 2012.

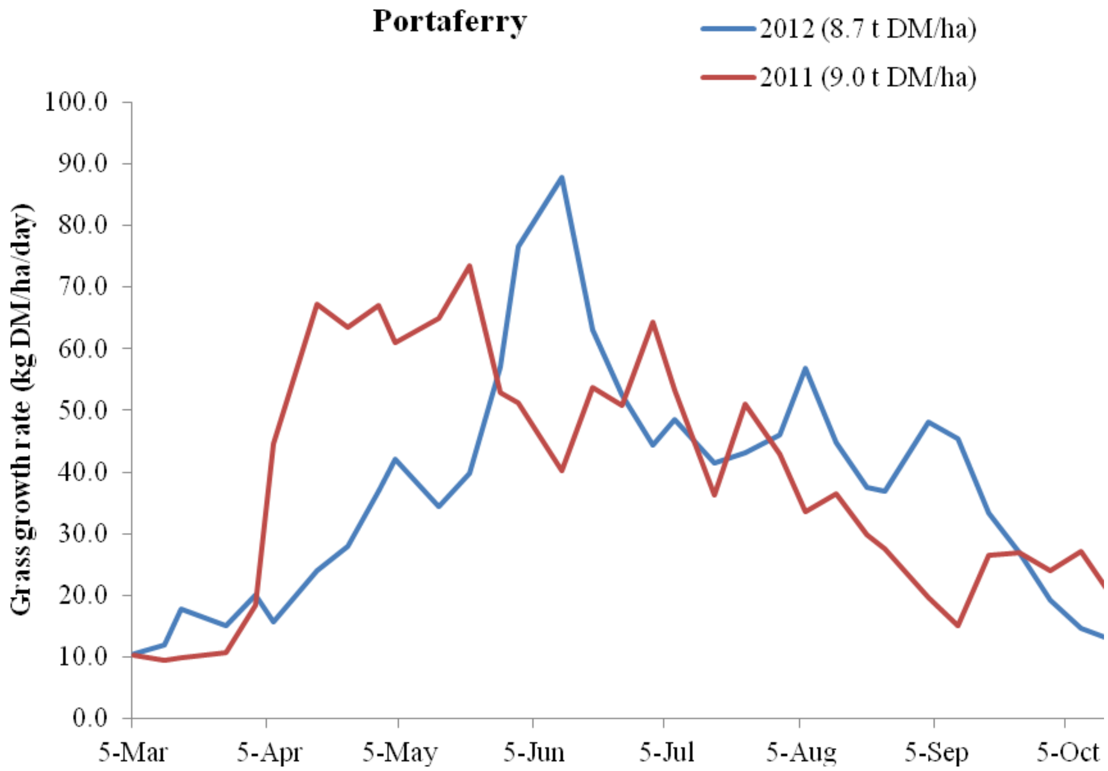
	Portaferry	Hillsborough	Greenmount	Aghadowey	Fintona	Tempo
05/03/2012	0.42	0.69	0.81	0.85	0.96	0.89
12/03/2012	0.42	0.83	0.88	0.84	0.91	0.87
19/03/2012	0.42	0.72	0.57	0.71	1.01	0.84
26/03/2012	0.37	0.74	0.57	0.64	0.87	0.83
02/04/2012	0.37	0.63	0.75	0.75	0.84	0.69
09/04/2012	0.32	0.65	0.58	0.78	0.82	0.73
16/04/2012	0.51	0.66	0.62	0.78	0.85	0.87
23/04/2012	0.48	0.79	0.61	0.80	0.94	0.84
30/04/2012	0.40	0.79	0.63	0.77	0.81	0.73
07/05/2012	0.37	0.71	0.58	0.70	0.85	0.68
14/05/2012	0.42	0.68	0.60	0.77	1.04	0.88
21/05/2012	0.39	0.71	0.61	0.77	0.90	0.87
28/05/2012	0.26	0.48	0.47	0.60	0.67	0.48
04/06/2012	0.23	0.45	0.44	0.56	0.60	0.62
11/06/2012	0.37	0.56	0.52	0.67	0.72	0.78
18/06/2012	0.40	0.65	0.68	0.71	0.80	0.78
25/06/2012	0.38	0.65	0.67	0.74	0.77	0.79
02/07/2012	0.38	0.62	0.58	0.76	0.77	0.73
09/07/2012	0.48	0.91	0.59	0.81	0.77	0.81
16/07/2012	0.43	0.61	0.62	0.72	0.84	0.75
23/07/2012	0.40	0.70	0.58	0.76	0.86	0.96
30/07/2012	0.43	0.73	0.64	0.79	0.82	0.89
06/08/2012	0.42	0.64	0.68	0.76	0.69	0.58
13/08/2012	0.47	0.59	0.70	0.76	0.73	0.62
20/08/2012	0.44	0.60	0.58	0.77	0.68	0.58
27/08/2012	0.45	0.66	0.67	0.76	1.02	0.89
03/09/2012	0.42	0.70	0.70	0.79	0.94	0.78
10/09/2012	0.42	0.63	0.56	0.82	0.86	0.84
17/09/2012	0.41	0.68	0.78	0.77	0.76	0.72
24/09/2012	0.48	0.75	0.66	0.81	0.84	0.76
01/10/2012	0.46	0.64	0.57	0.78	0.69	0.63
08/10/2012	0.46	0.61	0.78	0.81	0.95	0.87
15/10/2012	0.50	0.77	0.64	0.78	0.96	0.87

NB. At a soil moisture : dry soil ratio below 0.40, growth rates are likely to be reduced

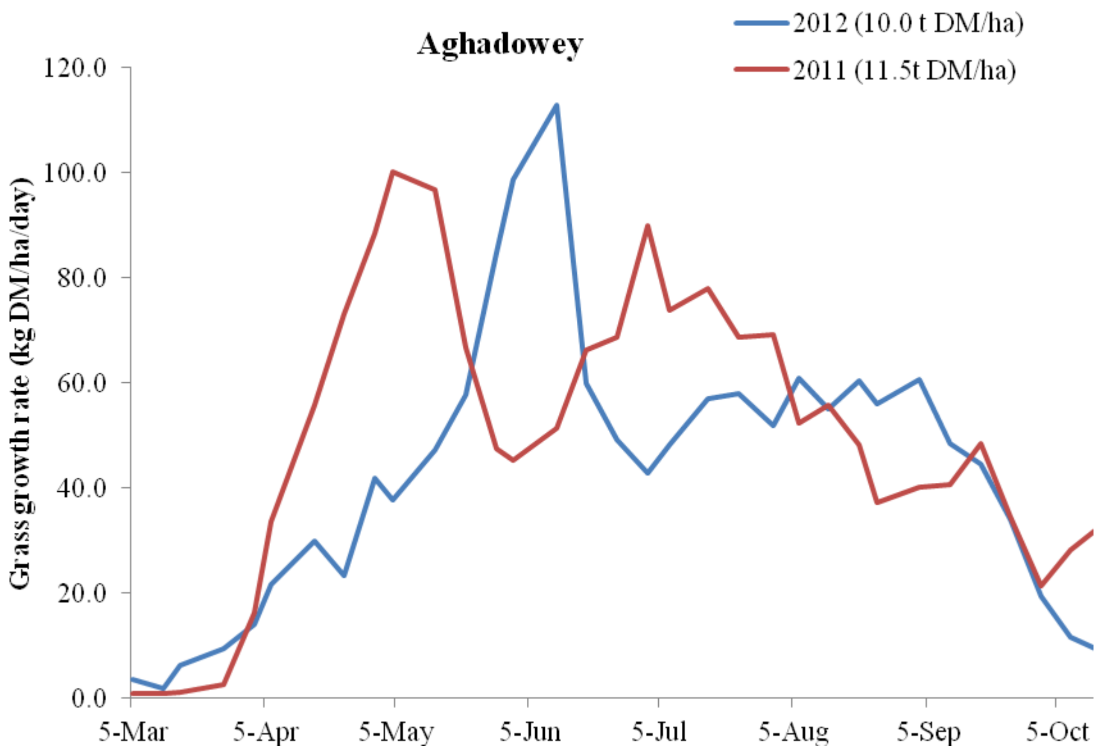
APPENDIX 9 The weekly grass growth and the total annual herbage production (t DM/ha) recorded at the Greenmount site during the two years of the project



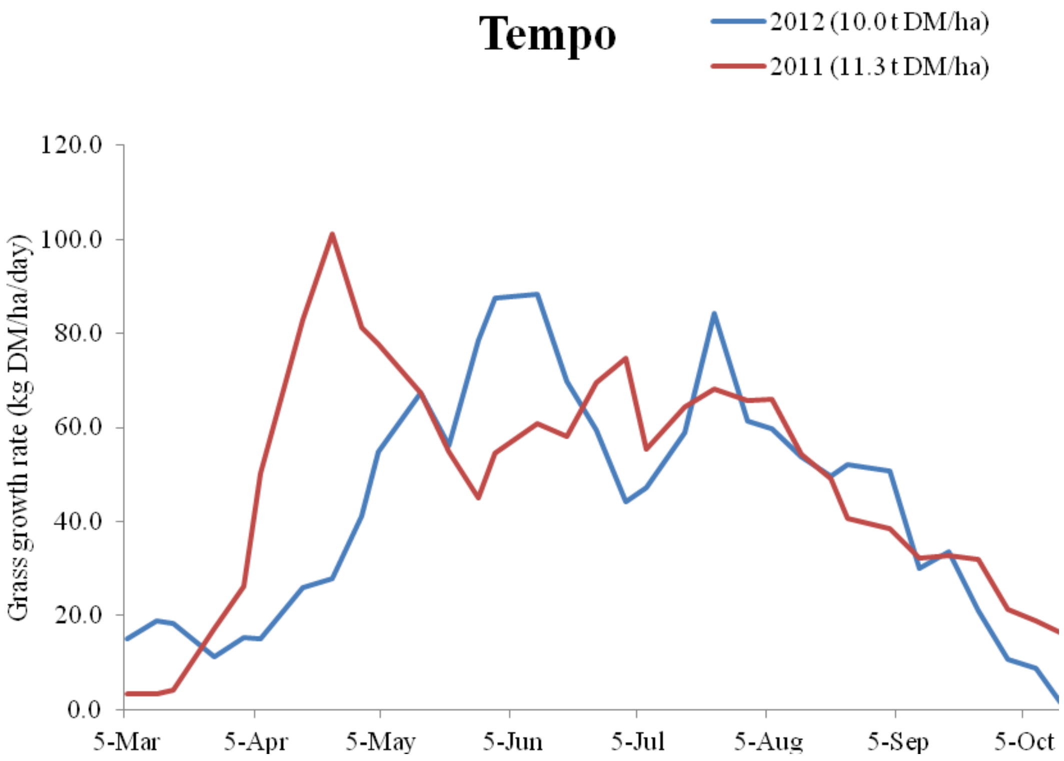
APPENDIX 10 The weekly grass growth and the total annual herbage production (t DM/ha) recorded at the Portaferry site during the two years of the project



APPENDIX 11 The weekly grass growth and the total annual herbage production (t DM/ha) recorded at the Aghadowey site during the two years of the project



APPENDIX 12 The weekly grass growth and the total annual herbage production (t DM/ha) recorded at the Tempo site during the two years of the project



APPENDIX 13 Weather summary for Hillsborough for 2011 and 2012

Date	Average Daily Max Air Temp °C	Average Daily Min Air Temp °C	Average Daily Air Temp °C	Average Daily Soil Temp °C	Total rainfall mm	Accumulated rainfall (mm)
05/03/11-18/03/11	7.6	0.4	4.0	5.6	3.1	3.1
19/03/11-1/04/11	12.5	3.0	7.8	6.7	0.4	3.4
02/04/11-15/04/11	15.3	5.4	10.3	8.9	1.4	4.8
16/04/11-29/04/11	15.0	5.2	10.1	9.8	0.1	4.9
30/04/11-13/05/11	15.3	7.2	11.3	10.6	1.5	6.4
14/05/11-27/05/11	13.6	6.4	10.0	10.9	2.1	8.5
28/05/11-10/06/11	15.3	6.9	11.5	11.9	1.6	10.1
11/06/11-24/06/11	15.6	6.8	11.2	12.4	3.5	13.6
25/06/11-08/07/11	18.4	8.5	13.4	13.7	1.8	15.4
09/07/11-22/07/11	17.0	9.7	13.4	14.3	2.3	17.7
23/07/11-05/08/11	19.2	10.1	14.6	14.6	0.9	18.7
06/08/11-19/08/11	17.3	9.8	13.5	14.6	3.1	21.7
20/08/11-02/09/11	16.9	9.3	13.1	14.0	0.6	22.3
03/09/11-16/09/11	16.0	10.1	13.1	13.4	3.8	26.1
17/09/11-30/09/11	16.3	10.0	13.2	12.9	2.7	28.8
1/10/11-14/10/11	15.8	9.4	12.6	12.9	7.6	36.4

Date	Average Daily Max Air Temp °C	Average Daily Min Air Temp °C	Average Daily Air Temp °C	Average Daily Soil Temp °C	Total rainfall mm	Accumulated rainfall (mm)
05/03/12-18/03/12	10.2	4.6	7.4	7.5	1.1	1.1
19/03/12-1/04/12	12.7	5.3	9.0	8.0	0.1	1.1
02/04/12-15/04/12	9.9	2.6	6.2	8.0	1.6	2.8
16/04/12-29/04/12	10.5	3.0	6.7	8.1	4.4	7.1
30/04/12-13/05/12	12.0	4.0	8.0	8.8	1.6	8.7
14/05/12-27/05/12	15.4	6.7	11.1	10.5	22.7	31.4
28/05/12-10/06/12	16.4	8.9	12.7	12.4	4.6	36.0
11/06/12-24/06/12	15.0	8.8	11.9	12.4	7.0	43.0
25/06/12-08/07/12	18.2	11.9	15.0	13.7	3.7	46.7
09/07/12-22/07/12	16.3	9.4	12.8	13.7	2.2	49.0
23/07/12-05/08/12	16.7	10.8	13.8	14.4	3.2	52.2
06/08/12-19/08/12	19.6	12.8	16.2	15.1	2.5	54.7
20/08/12-02/09/12	17.8	10.9	14.3	14.8	32.9	87.5
03/09/12-16/09/12	17.3	10.0	13.7	14.2	4.9	92.4
17/09/12-30/09/12	13.3	6.7	10.0	12.2	4.9	97.4
1/10/12-14/10/12	12.9	5.0	8.9	10.6	4.0	101.4

APPENDIX 14 Weather summary for Portaferry for 2011

Date	Average Daily Air Temp °C	Average Daily Soil Temp °C	Volumetric soil moisture m3.m-3	Total rainfall mm	Accumulated rainfall (mm)
07/03/11-20/03/11	5.99	6.26	0.00	0.00	0.00
21/03/11-03/04/11	8.92	8.79	0.59	5.00	5.00
04/04/11-17/04/11	10.33	11.06	0.54	8.40	13.40
18/04/11-01/05/11	11.46	12.47	0.40	1.60	15.00
02/05/11-15/05/11	11.74	12.99	0.46	37.40	52.40
16/05/11-29/05/11	11.46	12.61	0.50	18.00	70.40
30/05/11-12/06/11	12.05	14.62	0.53	44.40	114.80
13/06/11-26/06/11	13.28	15.35	0.56	45.40	160.20
27/06/11-10/07/11	14.11	16.89	0.47	19.60	179.80
11/07/11-24/07/11	14.37	17.07	0.41	9.60	189.40
25/07/11-07/08/11	15.53	17.82	0.28	13.40	202.80
08/08/11-21/08/11	16.52	14.48	0.32	18.00	220.80
22/08/11-04/09/11	15.32	13.67	0.26	21.2	242.00

APPENDIX 15 Weather summary for Fintona for 2011and 2012

Date	Average Daily Max Air Temp °C	Average Daily Min Air Temp °C	Average Daily Air Temp °C	Average Daily Max Soil Temp °C	Average Daily Min Soil Temp °C	Average Daily Soil Temp °C	Volumetric soil moisture m3.m-3	Total rainfall mm	Accumulated rainfall (mm)
07/03/11-20/03/11	5.00	3.88	4.44	4.90	4.81	4.85	0.903	46.80	46.80
21/03/11-03/04/11	9.28	8.01	8.64	7.94	7.83	7.88	0.899	28.00	74.80
04/04/11-17/04/11	11.66	10.39	11.03	10.61	10.48	10.54	0.897	29.80	104.60
18/04/11-01/05/11	12.51	10.98	11.75	11.49	11.33	11.41	0.896	0.40	105.00
02/05/11-15/05/11	12.21	10.76	11.49	12.06	11.93	12.00	0.897	58.20	163.20
16/05/11-29/05/11	11.01	9.76	10.38	12.28	12.17	12.23	0.898	90.00	253.20
30/05/11-12/06/11	12.72	10.81	11.77	13.28	13.16	13.22	0.895	58.00	311.20
13/06/11-26/06/11	13.91	12.27	13.09	13.99	13.88	13.94	0.894	55.20	366.40
27/06/11-10/07/11	15.61	13.69	14.65	15.54	15.42	15.48	0.892	46.20	412.60
11/07/11-24/07/11	14.50	13.21	13.85	15.48	15.39	15.43	0.894	21.20	433.80
25/07/11-07/08/11	15.42	14.15	14.79	15.75	15.64	15.70	0.892	16.80	450.60
08/08/11-15/08/11	14.79	13.64	14.22	15.50	15.42	15.46	0.892	48.80	499.40

Date	Average Daily Max Air Temp °C	Average Daily Min Air Temp °C	Average Daily Air Temp °C	Average Daily Max Soil Temp °C	Average Daily Min Soil Temp °C	Average Daily Soil Temp °C	Volumetric soil moisture m3.m-3	Total rainfall mm	Accumulated rainfall (mm)
05/03/12-18/03/12	12.2	11.5	11.8	12.5	12.1	12.3	0.9	1.2	1.2
19/03/12-01/04/12	9.8	8.5	9.2	9.1	8.8	9.0	0.8	2.8	4.0
02/04/12-15/04/12	6.6	5.2	5.9	7.9	7.7	7.8	0.9	35.4	39.4
16/04/12-29/04/12	7.3	5.7	6.5	8.8	8.5	8.7	0.9	43.0	82.4
30/04/12-13/05/12	8.5	7.1	7.8	10.0	9.7	9.9	0.8	57.4	139.8
14/05/12-27/05/12	13.0	11.6	12.3	13.2	12.9	13.1	0.8	19.6	159.4
28/05/12-10/06/12	13.8	12.4	13.1	15.7	15.5	15.6	0.7	87.2	246.6
11/06/12-24/06/12	12.3	11.1	11.7	14.2	14.1	14.2	0.8	89.2	335.8
25/06/12-08/07/12	15.6	14.5	15.0	16.6	16.4	16.5	0.8	88.4	424.2
09/07/12-22/07/12	13.8	12.4	13.1	15.7	15.5	15.6	0.8	29.6	453.8
23/07/12-05/08/12	14.9	13.6	14.3	16.4	16.3	16.3	0.8	80.6	534.4
06/08/12-19/08/12	17.2	15.9	16.5	17.2	17.1	17.2	0.8	77.0	611.4
20/08/12-02/09/12	14.8	13.6	14.2	16.4	16.4	16.4	0.8	43.8	655.2
03/09/12-16/09/12	13.9	12.7	13.3	15.7	15.5	15.6	0.8	4.6	659.8
17/09/12-30/09/12	10.3	9.2	9.7	12.3	12.2	12.2	0.8	8.6	668.4
1/10/12-14/10/12	7.9	6.7	7.3	10.3	10.2	10.3	0.8	33.0	701.4

APPENDIX 16 Weather summary for Tempo for 2011and 2012

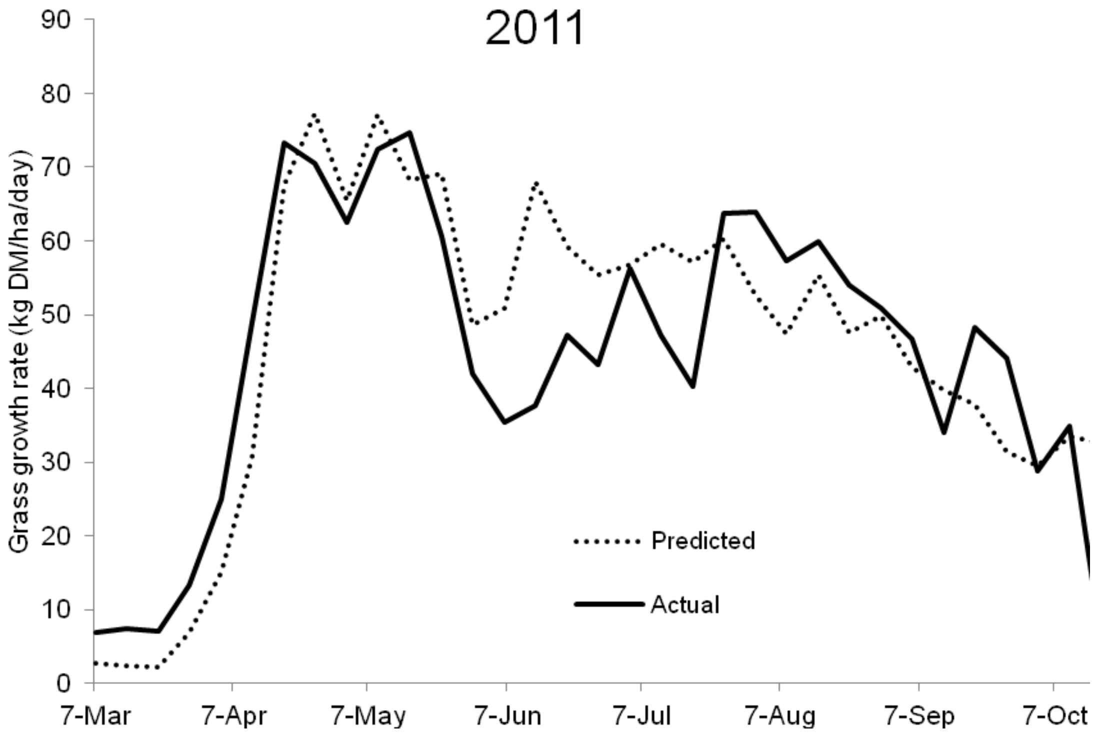
Date	Average Daily Max Air Temp °C	Average Daily Min Air Temp °C	Average Daily Air Temp °C	Average Daily Max Soil Temp °C	Average Daily Min Soil Temp °C	Average Daily Soil Temp °C	Volumetric soil moisture m3.m-3	Total rainfall mm	Accumulated rainfall (mm)
07/03/11-20/03/11	5.00	4.03	4.51	5.86	5.71	5.78	0.897	37.20	37.20
21/03/11-03/04/11	9.49	8.40	8.95	9.22	9.05	9.14	0.892	25.40	62.60
04/04/11-17/04/11	10.95	9.88	10.41	11.35	11.19	11.27	0.888	27.20	89.80
18/04/11-01/05/11	12.73	11.41	12.07	13.10	12.88	12.99	0.888	0.40	90.20
02/05/11-15/05/11	11.27	10.22	10.75	12.07	11.96	12.02	0.892	58.60	148.80
16/05/11-29/05/11	10.43	9.18	9.80	11.41	11.32	11.37	0.891	75.60	224.40
30/05/11-12/06/11	11.80	10.40	11.10	12.64	12.54	12.59	0.888	60.60	285.00
13/06/11-26/06/11	13.05	11.80	12.42	13.41	13.29	13.35	0.888	57.20	342.20
27/06/11-10/07/11	14.31	12.90	13.60	16.24	16.04	16.14	0.887	14.00	356.20
11/07/11-24/07/11	14.20	13.10	13.65	16.39	16.25	16.32	0.888	0.00	356.20
25/07/11-07/08/11	14.90	13.82	14.36	16.29	16.20	16.24	0.888	0.00	356.20
08/08/11-15/08/11	14.40	13.38	13.89	15.64	15.58	15.61	0.888	0.40	356.60

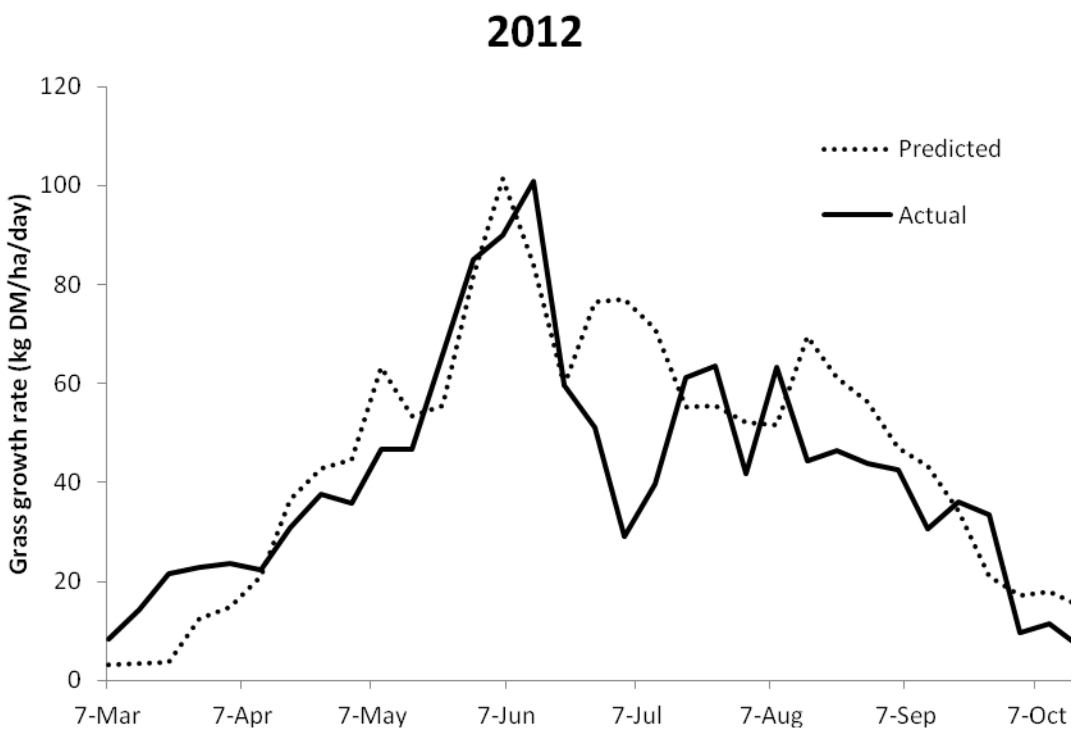
Date	Average Daily Max Air Temp °C	Average Daily Min Air Temp °C	Average Daily Air Temp °C	Average Daily Max Soil Temp °C	Average Daily Min Soil Temp °C	Average Daily Soil Temp °C	Volumetric soil moisture m3.m-3	Total rainfall mm	Accumulated rainfall (mm)
05/03/12-18/03/12	12.2	11.5	11.9	12.6	12.1	12.3	0.5	1.4	1.4
19/03/12-1/04/12	10.2	9.2	9.7	9.9	9.6	9.8	0.3	2.0	3.4
02/04/12-15/04/12	6.9	5.6	6.2	8.9	8.6	8.8	0.4	38.2	41.6
16/04/12-29/04/12	7.7	6.2	7.0	9.7	9.4	9.6	0.4	28.8	70.4
30/04/12-13/05/12	8.8	7.6	8.2	10.2	9.9	10.0	0.3	56.2	126.6
14/05/12-27/05/12	12.8	11.6	12.2	12.5	12.2	12.4	0.3	14.8	141.4
28/05/12-10/06/12	13.7	12.6	13.2	14.7	14.5	14.6	0.2	79.4	220.8
11/06/12-24/06/12	12.3	11.2	11.8	13.6	13.4	13.5	0.3	59.2	280.0
25/06/12-08/07/12	15.0	14.1	14.6	15.1	15.0	15.1	0.4	64.6	344.6
09/07/12-22/07/12	13.7	12.5	13.1	14.9	14.8	14.9	0.3	27.4	372.0
23/07/12-05/08/12	15.1	13.6	14.4	15.4	15.3	15.4	0.4	74.0	446.0
06/08/12-19/08/12	17.1	15.9	16.5	16.4	16.3	16.4	0.4	50.8	496.8
20/08/12-02/09/12	14.4	13.4	13.9	15.2	15.1	15.2	0.4	52.0	548.8
03/09/12-16/09/12	13.5	12.5	13.0	14.8	14.6	14.7	0.5	34.6	583.4
17/09/12-30/09/12	10.2	9.2	9.7	11.9	11.7	11.8	0.5	65.6	649.0
1/10/12-14/10/12	8.7	7.6	8.2	10.0	9.9	9.9	0.6	79.8	728.8

APPENDIX 17. Weather summary for Aghadowey for 2012

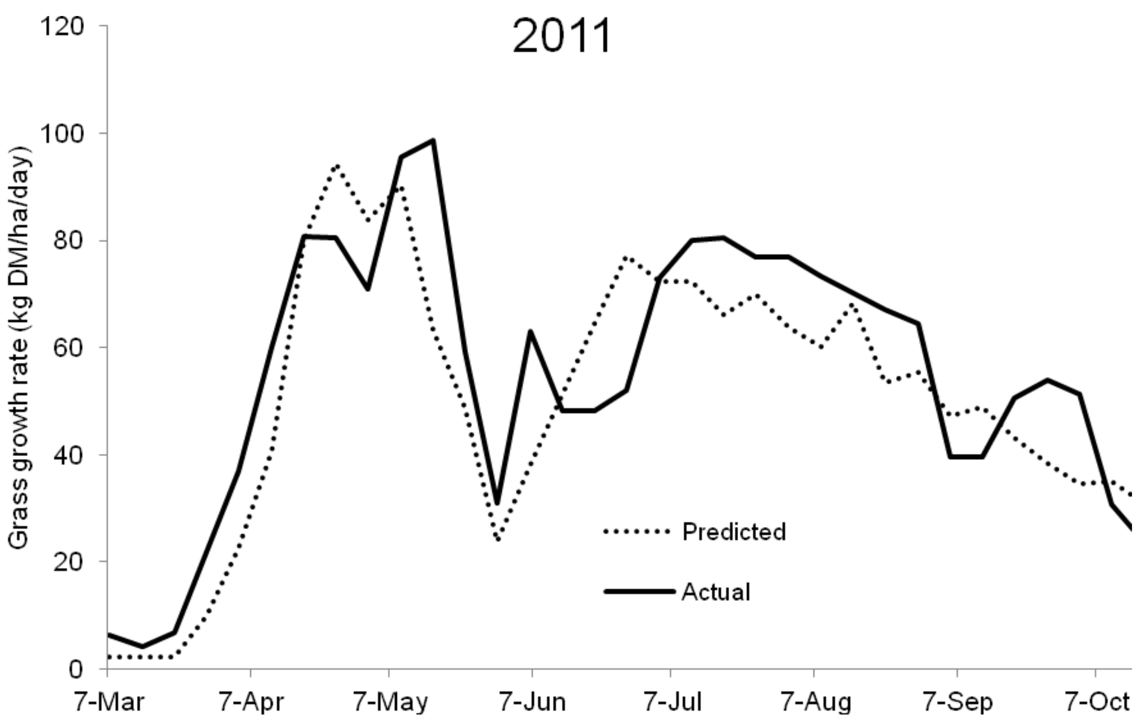
Date	Average Daily Max Air Temp °C	Average Daily Min Air Temp °C	Average Daily Air Temp °C	Average Daily Max Soil Temp °C	Average Daily Min Soil Temp °C	Average Daily Soil Temp °C	Volumetric soil moisture m3.m-3	Total rainfall mm	Accumulated rainfall (mm)
05/03/12-18/03/12									
19/03/12-01/04/12	14.3	14.0	14.2	14.0	13.7	13.8	0.5	0.2	0.2
02/04/12-15/04/12	7.3	6.0	6.7	8.1	8.0	8.0	0.6	22.2	22.4
16/04/12-29/04/12	7.7	6.4	7.0	8.7	8.6	8.6	0.6	33.0	55.4
30/04/12-13/05/12	8.8	7.5	8.1	9.6	9.5	9.5	0.6	35.2	90.6
14/05/12-27/05/12	13.6	12.1	12.9	12.1	12.0	12.0	0.6	35.6	126.2
28/05/12-10/06/12	13.9	12.6	13.2	14.7	14.6	14.7	0.6	24.6	150.8
11/06/12-24/06/12	12.4	11.3	11.9	13.4	13.3	13.4	0.6	112.4	263.2
25/06/12-08/07/12	15.6	14.6	15.1	15.7	15.6	15.7	0.6	56.0	319.2
09/07/12-22/07/12	13.9	12.8	13.3	14.9	14.8	14.9	0.6	30.0	349.2
23/07/12-05/08/12	15.1	13.7	14.4	15.8	15.7	15.7	0.6	46.8	396.0
06/08/12-19/08/12	16.8	15.5	16.1	16.9	16.8	16.8	0.6	40.4	436.4
20/08/12-02/09/12	15.3	14.0	14.7	16.1	16.0	16.0	0.6	30.0	466.4
03/09/12-16/09/12	14.2	13.1	13.6	14.7	14.7	14.7	0.6	18.0	484.4
17/09/12-30/09/12	10.8	9.7	10.2	11.7	11.7	11.7	0.6	56.2	540.6
01/10/12-14/10/12	9.3	8.0	8.6	10.3	10.2	10.2	0.6	46.2	586.8

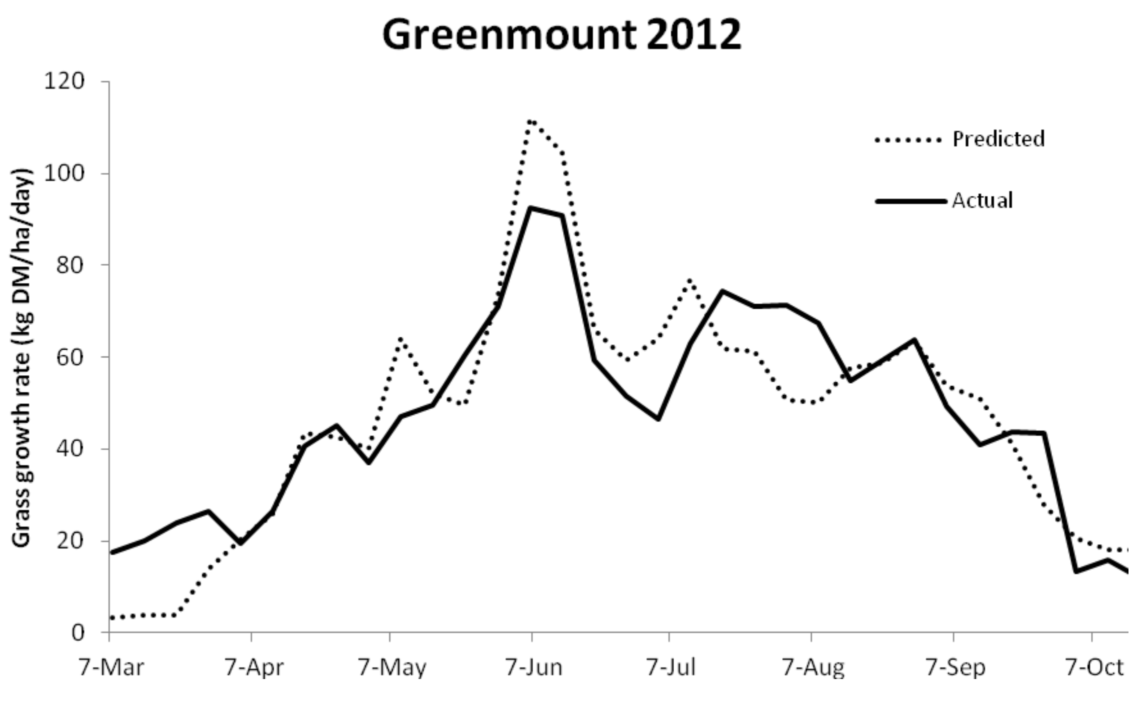
APPENDIX 18 Comparison of the grass growth simulated by the model and the actual grass growth recorded on the cut plots at Hillsborough during 2011 and 2012.



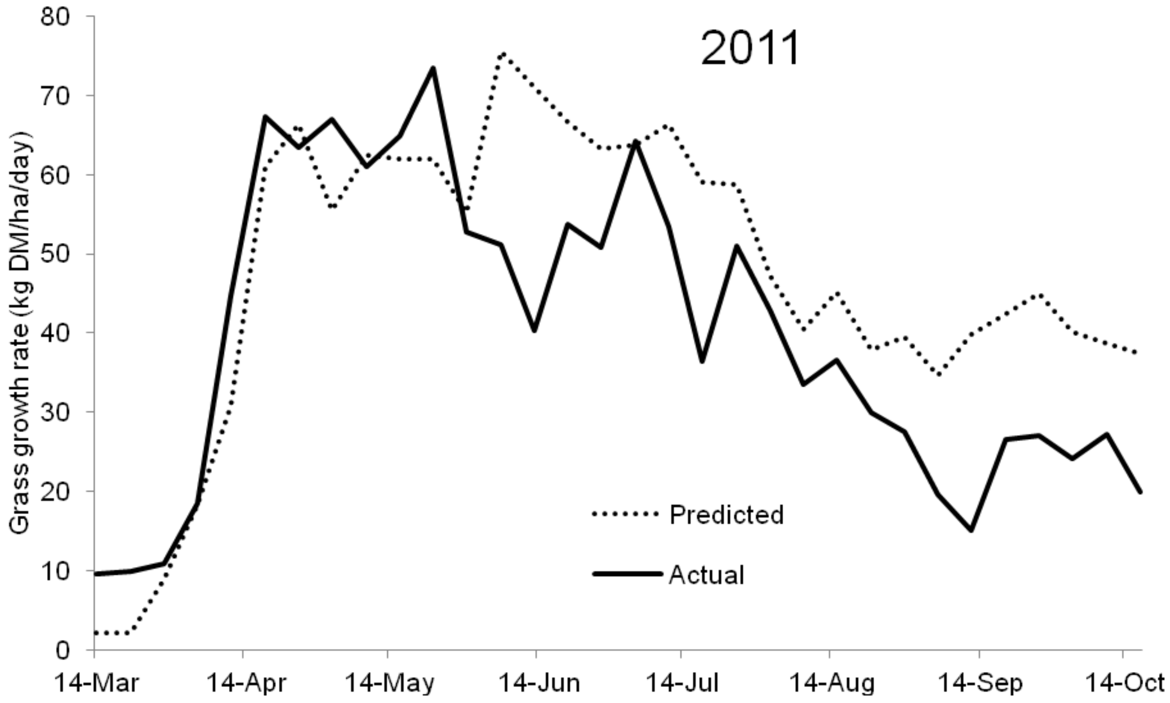


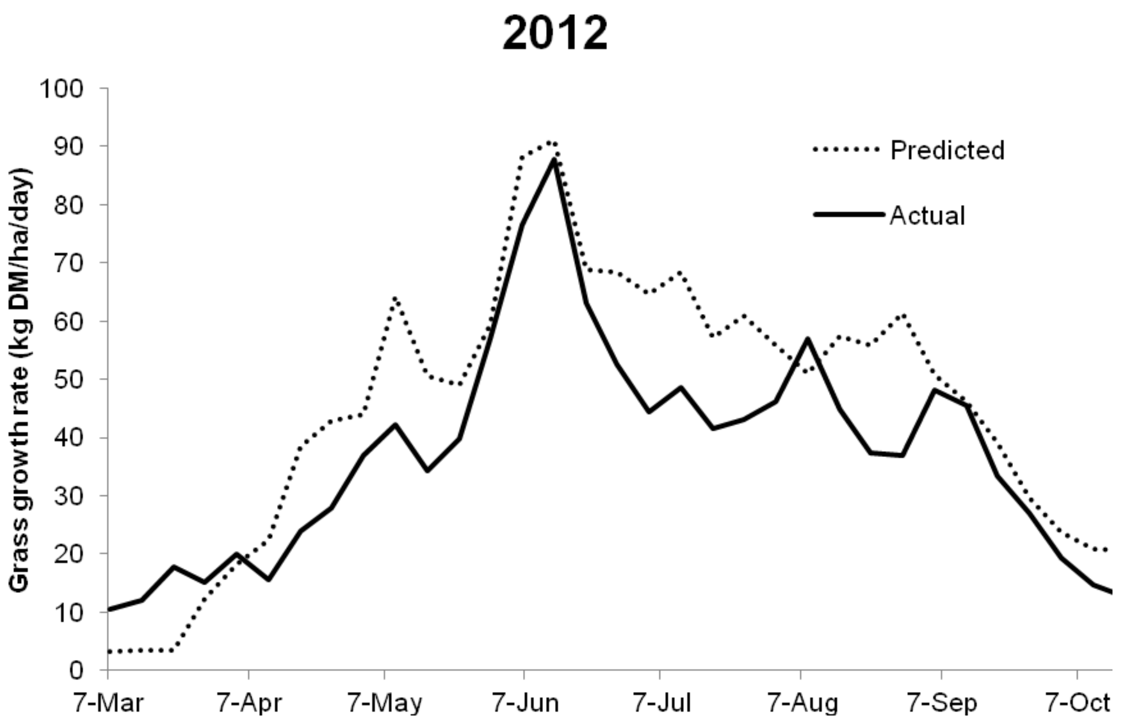
APPENDIX 19 Comparison of the grass growth simulated by the model and the actual grass growth recorded on the cut plots at Greenmount during 2011 and 2012.





APPENDIX 20 Comparison of the grass growth simulated by the model and the actual grass growth recorded on the cut plots at Portaferry during 2011 and 2012.





APPENDIX 21 Comparison of the grass growth simulated by the model and the actual grass growth recorded on the cut plots at Fintona during 2011 and 2012.