CONCEPT MODEL FOR MODERN CONTINUOUS STOCKING

1375 – Modern continuous stocking

Pim Klein Koerkamp

Peiyun Li

Marije Oostdam

Marieke Roseboom

Mohie El-Din Sherif

Commissioners: Marcia Stienezen and Bert Philipsen

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Commissioners

Marcia Stienezen
Wageningen UR Livestock Research
De Elst 1
6708 WD Wageningen
MARCIA.STIENEZEN@WUR.NL
0317-480765

Bert Philipsen
Wageningen UR Livestock Research
De Elst 1
6708 WD Wageningen
BERT.PHILIPSEN@WUR.NL
0317-480731

Secretary

Marije Oostdam
MARIJE.OOSTDAM@WUR.NL
0651855816

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EXECUTIVE SUMMARY (ENGLISH)

This report analysed the modern continuous stocking system for dairy farms in the Netherlands. This system has to deal with a minimum grass height of 8 or 10cm (depending on the season) in order to obtain maximum grass production. A model should predict the available herbage mass under changing weather conditions and therefore the available fresh grass and the related amount of additional feed needed for the cows. A concept model, called McGraze, is developed for farmers in order to manage modern continuous stocking (Figure 1). McGraze consists of a grass production section and a stoking related section. The grass production section is based on an existing grass production model called LINGRA, which resulted from a literature review to be the most accurate model to predict grass production. LINGRA needs some minor changes in order to fit into McGraze. The stocking related section is key to the final hours of stocking and the related additional feeding, which are the outputs of McGraze. All values used to predict the outputs are a result of a literature study on grass height, grass quality, grass intake and the effect of stocking on grass growth.

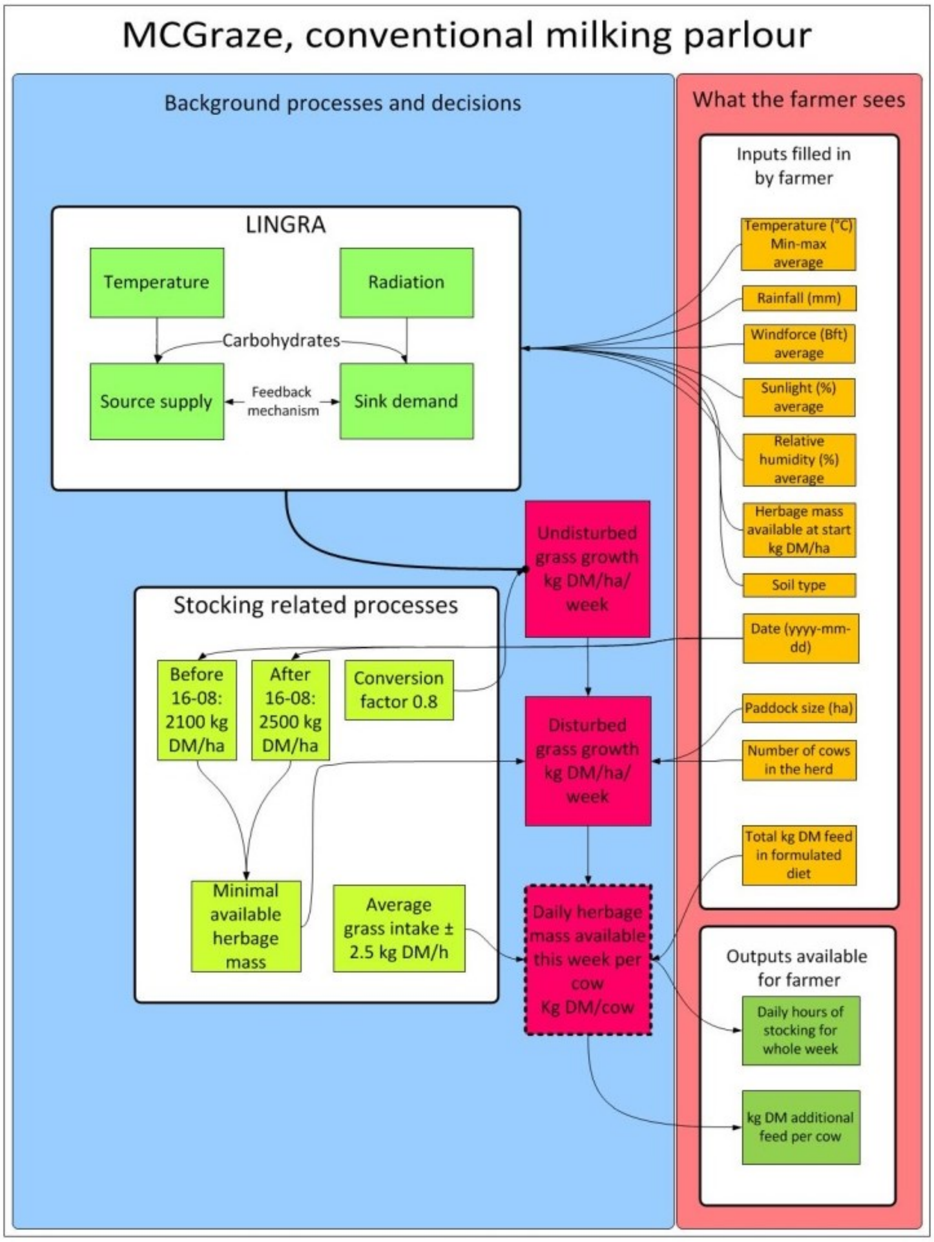


Figure 1. Flowchart for McGraze

The input section of McGraze needs to be filled in by farmers. After that, the background process which will run automatically in order to obtain the output.

Inputs for McGraze are:

1. Date
2. Temperature
3. Rainfall
4. Wind force
5. Sunlight
6. Relative humidity
7. Soil type
8. Herbage mass available at start
9. Paddock size
10. Number of cows in the herd
11. Total feed in formulated diet
12. Average grass intake
13. Minimum available herbage mass
14. Conversion factor

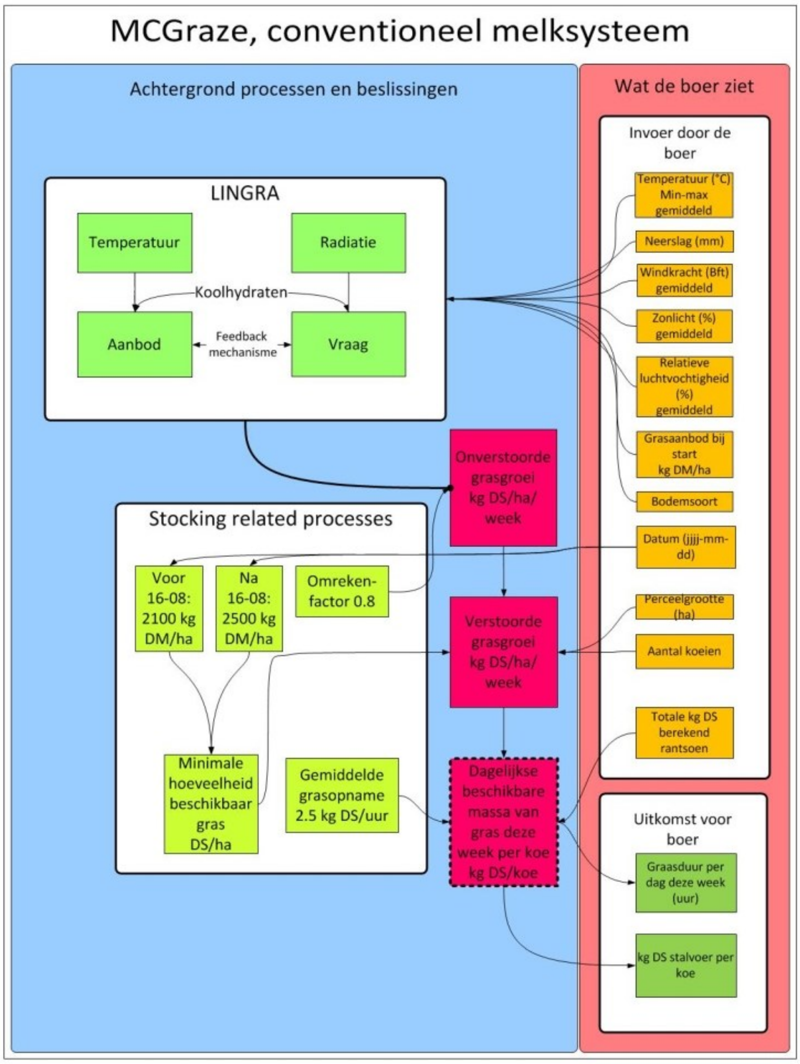
Inputs 1 to 6 are all related to the weather, inputs 7 and 8 related to the pasture and they are all inputs for the LINGRA part of McGraze. Numbers 9 to 14 are all stocking related processes in McGraze. All interactions and values can be seen in the figure. The minimum grass height to be obtained before 16th of august is 8cm (corresponding with 2100kg DM/ha) and after that date the minimum grass height is 10cm (corresponding with 2500kg DM/ha). A conversion factor of 0.8 is used to correct the predicted grass production of LINGRA for dung and urine spots and the stocking itself. This will give the disturbed grass growth and together with the average grass intake of 2.5kg DM/h it will lead to the daily hours of stocking and the amount of additional feed needed.

This documentation also provides advices for management factors of modern continuous stocking related to the rotation, automatic milking system, grass cover and a disclaimer.

In order to make it into a real working program, this documentation of McGraze should be handed to a programmer or model expert. Eventually McGraze should be validated by testing it in practice. In the future, more advanced techniques may be applied to the model like satellite and GPS information.

EXECUTIVE SUMMARY (DUTCH)

Dit verslag analyseert het moderne standweiden (MS) bij melkveebedrijven in Nederland. Het beweidingssysteem heeft te maken met een minimum grashoogte van 8 of 10cm, afhankelijk van het seizoen, om maximale grasproductie te behalen. Een voorspelling van de hoeveelheid beschikbaar gras, welke wordt beïnvloed door wisselende weersomstandigheden en de balans met stalvoeding moet gemaakt worden door een model. Een concept model, McGraze genaamd, is ontwikkeld voor melkveehouders voor het managen van MS (Figuur 1). McGraze bestaat uit een grasproductie deel en een beweidingdeel. Het grasproductie deel is gebaseerd op een bestaand gras productie model, genaamd LINGRA, welke uit een literatuurstudie naar voren kwam als het meest nauwkeurig voorspellende model van grasproductie. Een aantal aanpassingen moeten gemaakt worden om LINGRA in McGraze te passen. Het beweidingdeel wordt hier aan toegevoegd om uiteindelijk de voorspelling te maken op weekbasis van het aantal beweidings-uren en de hoeveelheid stalvoeding die bijgevoerd moet worden. Alle waarden die worden gebruikt om de uitkomst te bepalen zijn gebaseerd op literatuurstudies over grashoogte, graskwaliteit, gras-inname en het effect van weidegang op de groei van gras. De invoer voor McGraze dient door melkveehouders ingevuld te worden. Vervolgens maakt het model berekeningen en wordt de uitkomst weergegeven.



Figuur 1. Flow-diagram van McGraze

De gegevens die een melkveehouder moeten invoeren zijn:

1. Datum
2. Temperatuur
3. Neerslag
4. Windkracht
5. Zonlicht
6. Relatieve vochtigheid
7. Grondsoort
8. Massa van het gras, beschikbaar bij de start
9. Areaal
10. Koppelgrootte
11. Totale voer in geformuleerd rantsoen
12. Gemiddelde grasopname
13. Minimale hoeveelheid beschikbaar gras
14. Omrekenfactor

Nummers 1 tot 6 zijn weer-gerelateerd en nummers 7 en 8 hebben betrekking op het weiland. Dit is de invoer voor LINGRA in McGraze. Nummers 9 tot 14 zijn beweiding gerelateerde processen in McGraze. Alle interacties en waarden zijn te zien in figuur 1. De minimale grashoogte vóór 16 augustus is 8cm (corresponderend met 2100kg droge stof/ ha) en na 16 augustus wordt de minimale grashoogte 10cm (corresponderend met 2500kg droge stof/ ha). De omrekenfactor wordt gebruikt om de voorspelde gras productie te corrigeren voor grasverlies wat optreed door beweiden. Dit resulteert in verstoorde grasgroei, wat samen met de gemiddelde gras inname van 2,5kg droge stof per uur leidt tot het aantal beweidingsuren en de hoeveelheid stalvoeding wat moet worden bijgevoerd.

Daarnaast worden in dit verslag de management factoren behandeld die niet aan McGraze toegevoegd kunnen worden, maar wel belangrijk zijn voor boeren om mee te nemen in het management van MS. Deze studie bevat alleen een concept-model, McGraze zal verder ontwikkeld moeten worden door grasland- en modelleer-experts, zodat het gevalideerd en getest kan worden op het gebruik door boeren.

SCIENTIFIC SUMMARY (ENGLISH)

In the Netherlands, dairy farmers are experiencing difficulties managing their pasture using modern continuous stocking. Due to changing weather conditions, farmers experience difficulties in managing grass production and, therefore, the amount of additional feed needed to maintain optimal grass growth and milk yield. Thus, it is the objective of this study to develop a concept model for a MCS management tool under the name McGraze. In McGraze, an existing model called LINGRA was used for predicting grass production. However, several adjustments were proposed on LINGRA to adapt it for McGraze based on literature and interviews with farmers. Because LINGRA only predicts grass production, factors related to stocking management (e.g. the consumption of grass by cows and the effect of grazing on grass production) were also proposed to be included in McGraze. Besides, this report discusses the management factors that cannot be incorporated in McGraze, nevertheless important for farmers to take into account while managing MCS. Being just a concept model in this documentation, McGraze should be further developed by grassland- and model-experts so that McGraze could be validated and tested for it to be applicable for use by farmers.

Keywords: Modern continuous stocking, grass production, management tool, LINGRA, Netherlands

SCIENTIFIC SUMMARY (DUTCH)

Nederlandse melkveehouders hebben problemen met weidemanagement voor modern standweiden (MS). Door veranderende weersomstandigheden, hebben boeren problemen met het management van de grasproductie en, als gevolg, de hoeveelheid stalvoer om de grasopbrengst en melkopbrengst optimaal te houden. Daarom is het doel van deze studie om een concept-model te ontwikkelen voor een managementprogramma voor MS, genaamd McGraze. In McGraze, is het bestaande model LINGRA gebruikt voor het voorspellen van grasproductie, factoren gerelateerd aan beweiden (bijv. grasconsumptie van koeien en het effect van grazen op de grasproductie) worden voorgesteld toegevoegd te worden aan McGraze. Daarnaast worden in dit verslag de management factoren behandeld die niet aan McGraze toegevoegd kunnen worden, maar wel belangrijk zijn voor boeren om mee te nemen in het management van MS. Deze studie bevat alleen een concept-model, McGraze zal verder ontwikkeld moeten worden door grasland- en modelleer-experts, zodat het gevalideerd en getest kan worden op het gebruik door boeren.

Kernwoorden: modern standweiden, grasproductie, managementprogramma, LINGRA, Nederland

CONTENT

Preface

The documentation you have in your hands now, is a result of two months of work of five master students Animal Science. This report is a part of the course ACT, Academic Consultancy Training, a course to provide students the possibility to work in a team on a 'real world' project for an external client.

During this project we were able to translate the problem of our commissioner, the lack of a management tool for modern continuous stocking, into a solution. Therefore, we created a concept model and together with an extensive literature review, it ended up as the documentation in your hands.

Our group consists of five master students Animal Science, four with the specialisation of Animal Nutrition and one with a specialisation in Animal Production Systems, who have never met or worked with each other before. In addition, to end this period with a satisfied commissioner and a decent documentation, we needed to become a team instead of five individuals. During this project, we learned to work together and we were able to put everyone's talents in the right spot. Marieke, our manager, guided us through every meeting and made sure the progress was going smooth. Marije, our secretary, took care of the e-mails and time schedule we made. Beside she was the brain behind the concept model. Pim, our accountant, took a good care of our budget and was critical towards the content of the project. Mohie, always looking into all the literature and he brought a big effort to the team spirit by making sure that we had fun. And last, Li, calm as she is, always working hard and bringing new ideas and perspectives on the table. With this project ending, we can all say that we learned a lot. We learned to work together, improving our consultancy skills, communication skills and academic skills.

Overall, we want to thank everyone involved in this project for their contribution, feedback and support, leading towards this end product that might be a basis for future developments on this subject.

We wish you a pleasant and informative time, reading our report about McGraze.

Li, Marieke, Marije, Mohie and Pim

ACT-team: Modern continuous stocking

1. INTRODUCTION

In the Netherlands, grazing itself does not provide enough feed for the cows, therefore additional feeding is always needed to maintain the high milk yield (Kolver and Muller 1998). In order to manage the feed available in the pasture, farmers need to manage their grassland and stocking management. There are several stocking strategies (e.g. rotating, continuous or strip stocking). The stocking system considered in this case is modern continuous stocking (MCS).

No clear definition about MCS currently exists, so in order to come up with a good description of this system, interviews with several farmers and experts were conducted. The system of MCS divides the pasture into three large paddocks. Cows will graze in one paddock for approximately three weeks, before moving to another paddock (Figure 1).

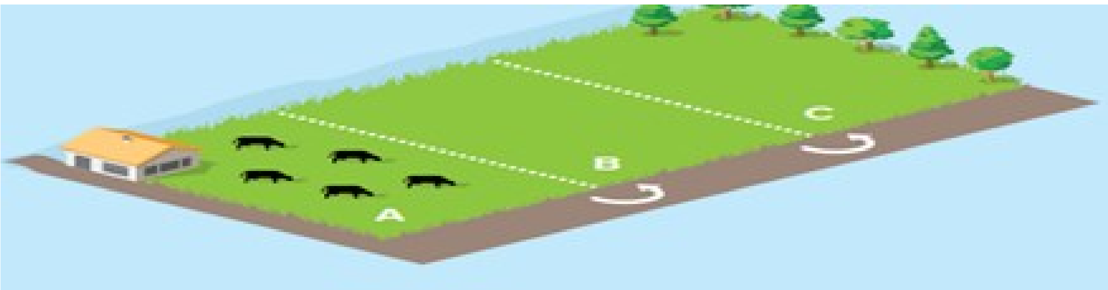


Figure 1. Division of pasture paddocks (A, B and C) in MCS(Stichting Weidegang 2012).

In order to maintain maximum grass production under MCS, the optimal stocking method will be maintaining a grass height of 8-10cm (van den Pol-van Dasselaar et al. 2014). A small literature review on the optimal grass height can be found in chapter 4.2. The advised stocking rate is 10-20 cows per hectare where they are only allowed to graze during daytime with a maximum of 12 hours per day. Figure 2 shows a grazing schedule under MCS. In this case three different paddocks existing of four parcels (green) are used. One paddock will be used for stocking, meanwhile one other paddock will be rest to grow and the last paddock will be mowed (red stripes). This is the circle of the system: first stocking, then growing and finally mowing. After mowing, the grass is not grazed in order to let it regrow until a height of 8-10cm before cows will enter the paddock.

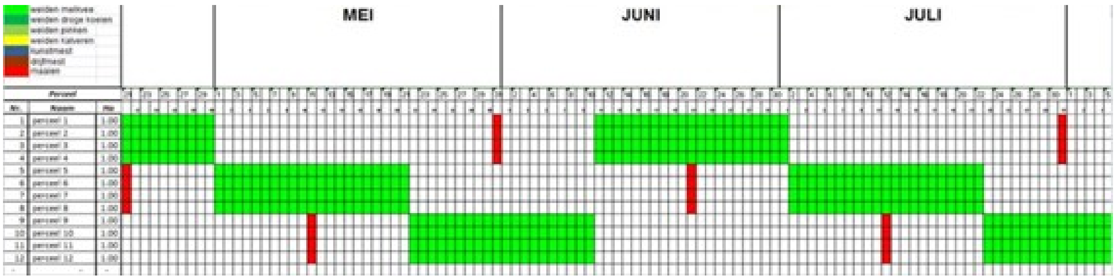


Figure 2. Grazing schedule used for MCS (Stichting Weidegang 2012).

1.1 CONCEPT MODEL FOR MANAGEMENT TOOL

Inducement of this project came from Wageningen Livestock Research in the project of Amazing Grazing, it is noticed that some farmers face problems using MCS on their farms. Farmers are lacking a management tool in order to manage their stocking system. In order to maintain grass height at 8-10 cm and keeping milk yield at the same level, farmers need to change the amount of additional feed due to grass growth and grass quality. The main questions of the farmers where "what will be the grass production of this week" and "how much additional feed do we need to supply in order to maintain grass height and milk yield". In order to find a solution for the farmer's problems a concept model for a management tool for modern continuous stocking will be developed.

The management of MCS is influenced by several external factors, that even may change over time and season (e.g. grass growth, grass quality, dry matter intake, stocking rate, height grass and weather conditions). Via Wageningen Livestock Research, the farmers asked for a management tool that would help them dealing with the changing circumstances. In the end, farmers want a management tool, that is easy to use and gives a good estimation of what actually happens. Due to limited resources, this product consists of a concept for a model (McGraze) that can be used for the development of an actual management tool for MCS.

McGraze consists of three major parts: the inputs that the farmer needs to fill in, the outputs the farmer will get from the tool and a part that runs on the background that creates output from the given inputs. For every part, especially the processes that are involved in the background, documentation is given. Also for other related processes and factors that might influence the management of MCS, documentation is provided.

1.2 Overview documentation

In chapter 2, 3 and 4 the underpinning of the decisions and evidence used for building McGraze can be found. This documentation can be used for further developing a full management tool.
Grass growth can be predicted and is influenced by a large amount of sub-processes. For McGraze an existing model is used for prediction of grass production, called LINGRA (Bouman et al. 1996). This documentation starts with a review on existing models in chapter 2 and an explanation of LINGRA in chapter 3. Afterwards, adjustments and additions are suggested for LINGRA based on the interviews with the farmers and literature (chapter 3 and 4). Since LINGRA only predicts grass production, the stocking management is included in McGraze. The stocking management consists of several factors influencing grazing, such as the consumption of grass by cows and the effect of grazing on grass production. Finally, this documentation consists of a number of management factors that cannot be included in McGraze, but are essential for farmers to keep in mind while managing MCS (chapter 5).

2. EXISTING MANAGEMENT TOOLS FOR STOCKING

An important part of a management tool for MCS is the interaction between grass production and the grass intake. Therefore, an important component is the choice of a good grass growth model (Barrett and Laidlaw 2005). Since it is more convenient to adopt and improve an existing and validated grass growth model for the purpose of this project, a review of existing models is used in order to come up with the most suitable model for this case (Barrett and Laidlaw 2005). The grass growth that is predicted in the models is depending on a lot of input. Different meteorological factors influence grass growth at different times of the year. Hurtado-Uria et al. (2013) found significant changes in monthly weather patterns in all meteorological variables studied (maximum, minimum and mean air temperature, soil temperature at 50mm and at 100mm, sunshine hours, solar radiation and rainfall). Hurtado-Uria et al. (2013) concluded that it may be possible to use meteorological data to predict grass growth, although management factors will contribute to grass growth rate as well. To first explain some general facts about grass growth, figure 3 shows the calculated seasonal pattern of net grass production under continuous stocking for a number of radiation levels. For the calculations the following conditions were assumed to exist (Lantinga 1985):

1. Mean daily temperature of 15 °C;
2. Mean sward height of 7-8 cm (for measurement chapter 4.1);
3. Optimal supply of water and nutrients.

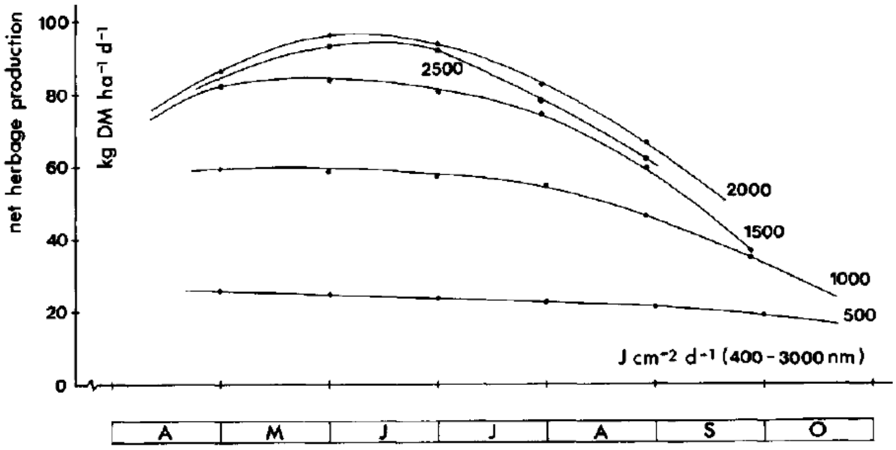


Figure 3. Seasonal pattern of net grass production from April to October (Lantinga 1985)

2.1 E-COW

e-Cow is an model that predicts herbage intake, milk yield and live weight change in cows grazing temperate pastures, with and without additional feeding (Baudracco et al. 2012). e-Cow only takes the cow characteristics of grazing into account. Inputs of this model are herbage allowance (kg dry matter (DM) offered/cow/day), metabolisable energy (mega joule (MJ)/kg DM) and neutral detergent fibre (NDF (%kg/DM)) in herbage and supplements, supplements offered (kg DM/cow/day), type of pasture (ryegrass or *Lucerne*), lactation stage, gestation days, parity, body condition score, live weight at calving, breed of cows and genetic merit (potential yield of milk, fat and protein) (Baudracco et al. 2012). The whole-lactation performance of the cow can be predicted with this model, where the main outputs are daily DM intake, milk production, changing live weight and body condition scores of the cow. This is a very detailed model and can be very interesting for farmers. However, if this will be included in McGraze, there will be a lot of inputs per cow that farmers have to include. e-Cow is interesting to use for the amount of concentrates that should be fed to a cow in a certain lactation stage, but McGraze will focus on herd management.

2.2 GrazeVision and DairyWise

GrazeVision is a decision support model for farmers to predict the effects of grazing management on animal and grassland production (Zom and Holshof 2011). This grazing decision model is incorporated in the DairyWise whole-farm decision model (Zom and Holshof 2011; Schils et al. 2007). The existing models, Grass Growth Model, Grass Intake Model and Animal Production Model are all sub-systems in GrazeVision. Figure 4 shows the inputs and outputs of GrazeVision and their interactions. The inputs to predict the grass growth are: nitrogen fertilization, soil type, water supply and the date of year, which are inputs for the Grass Growth Model. The applicable part of the Grass Growth model is described in chapter 4.4.2, the grass loss due to urine and dung spots. The second inputs are the management factors: paddock size, access time to pasture, topping and stocking rate. The third input group concerns cow characteristics and milk production, which are the inputs for the Grass Intake Model. The fourth group includes level of supplemental forage, concentrate feeding and feed characteristics which are also part of the Grass Intake Model or are a sub-division to use in the Animal Production Model (Zom and Holshof 2011). The outputs of the model are grass allowance, grass intake, utilization percentage of total allowance and potential milk production. This model can be used for rotational grazing and permanent grazing.

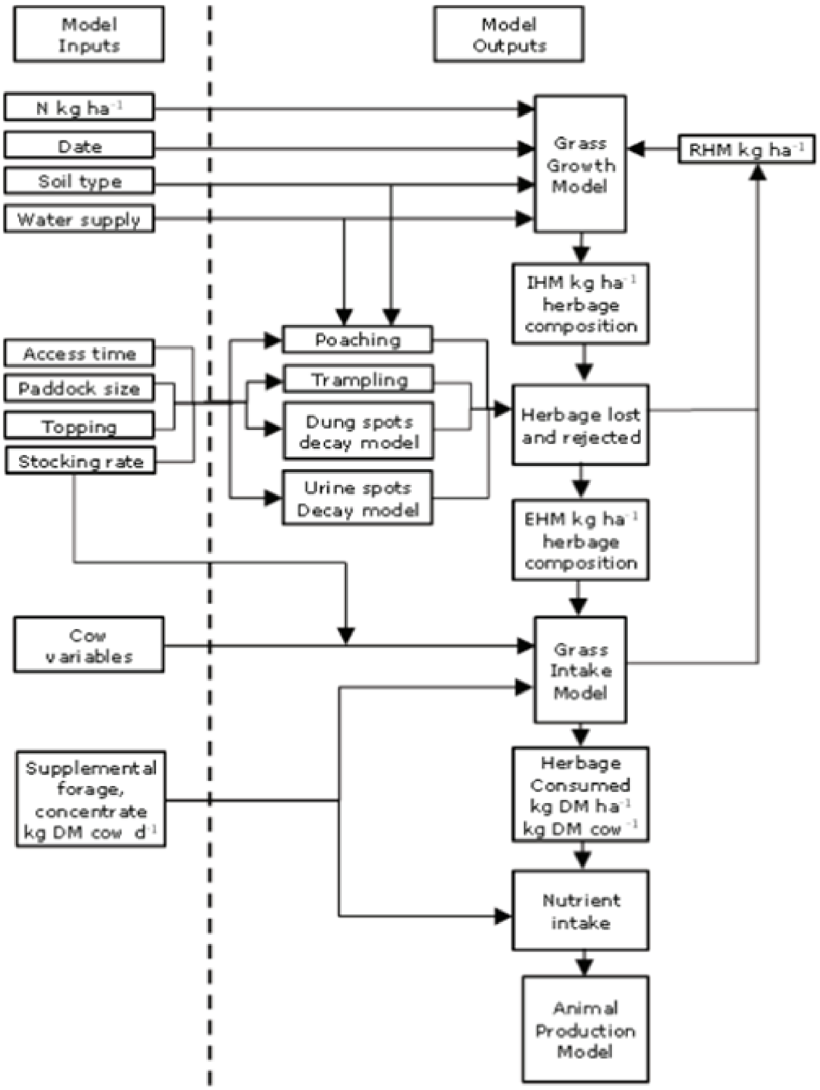


Figure 4. Flow-chart of GrazeVision (Zom and Holshof 2011)

GrazeVision is a very good decision support model. however, the inputs and outputs are not all useful in McGraze. Interviews with the farmers made clear that it is difficult for them to maintain the grass at a certain height, especially under changing weather conditions. GrazeVision starts with a certain grass height (pre-grazing grass height) and estimates the post-grazing grass height. So, herbage mass and allowance height (kg DM/ha) decrease over the period instead of maintaining it on a constant level. GrazeVision keeps the feed intake per cow and the hours of stocking constant. For McGraze, the grass height is constant and the average intake at grazing (kg DM/cow/day) is changing. Also, GrazeVision assumes that grass production is not affected by weather conditions, only consumption of grass by cows is affecting grass production.

2.3 GrazeMore project

In 2004 the European Union started to fund a research project (GrazeMore) which aimed to develop a decision support system for grazing (Mayne et al. 2004). The two models developed, GrazeGro and GrazeIn, predict seasonal grass production and grass intake of grazing cows.

2.3.1 GrazeGro

GrazeGro is a European grass growth model to predict pasture production in *Lolium perenne* swards (Barrett et al. 2005). The GrazeMore project modified and recalibrated LINGRA to meet the requirements of the GrazeMore project (For LINGRA, chapter 3). Additions of GrazeGro to LINGRA are: reproductive growth, growth response to soil nitrogen, changes in herbage quality in the form of crude protein (CP), organic matter (OM) digestibility and the production of *Trifolium Repens* (white clover) in a mixed sward.

2.3.2 GrazeIn

GrazeIn predicts total DM intake, potential milk production and actual milk production according to diet offered under rotational or continuous stocking systems (Delagarde et al. 2011). Total DM intake prediction by GrazeIn is explained in detail in chapter 4.5.4. Table 1 shows the indicators which are used to predict the potential milk production. Prediction of actual milk production according to diet offered is based on the potential milk production and total DM intake (Faverdin et al. 2011; Delagarde et al. 2011).

Table 1. Animal characteristics used in GraezIn to predict potential milk production (Faverdin et al. 2011)

Animal characteristics	Unit
Primiparous or multiparous	-
Days in milk	day
Maximum milk potential production of the lactation	kg/day
Days since last calving at fertilizing insemination	day
Body condition score	scale 0-5
Live weight	kg
Age of cow	month
Week of gestation	week
Week of lactation	week

2.4 Evaluation of grass production models

Over the last years, several models are made to predict grass production. Which model is most accurate in predicting grass production was tested by Van den Pol-van Dasselaar et al. (2011) and Barrett et al. (2005). Van den Pol-van Dasselaar et al. (2011) tested three models in Ireland and Barrett et al. (2005) tested four models in both Northern Ireland and England. The outcome of both tests will now be explained.

2.4.1 Van den Pol-van Dasselaar

Since dairy production in Ireland is predominantly grass-based, it is not surprising that several models are made to predict grass production in Ireland. Predicting grass production in Ireland can be challenging due to climatic factors (Van den Pol-van Dasselaar et al. 2011). Several grass production models exist and Van den Pol-van Dasselaar et al. (2011) compared the accuracy of prediction of three grass production models. Climate and grass growth data from Teagasc Moorepark Dairy Production Research Centre (Ireland) over the last three years were used to compare the models (O'mara 2013). The three models that are compared are:

1. Agrometeorology of grass, made by Brereton et al. (1996), indicates the importance of climate on the composition, development and utilization of grass. The impact of radiation, temperature and rainfall on grass production is taken into account. Also soil fertility and the effect of wind are included.
2. The English vegetative crop growth model, made by Johnson and Thornley (1983), simulates the time course of grass DM production and leaf area development of grass, that is exposed to a constant environment, a seasonally-variable environment and defoliation.
3. A French model, made by Jouven et al. (2006), simulates the dynamics of herbage mass, structure and digestibility of grass at the field and farm scales for a wide range of management regimes.

As mentioned before, Van den Pol-van Dasselaar et al. (2011) evaluated the prediction accuracy of the models. Figure 5 shows the outcomes of the observed grass growth rates in Moorepark (Ireland) and the three predicted grass growth rates by the models.

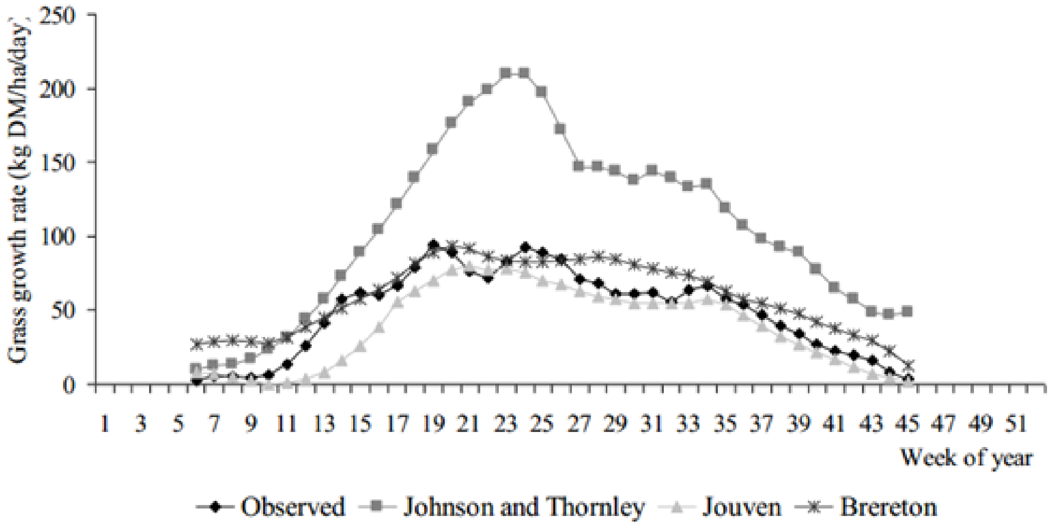


Figure 5. Observed and predicted Moorepark grass growth rate (kg DM/ha/day) for 2005 (Van den Pol-van Dasselaar et al. 2011)

The model of Jouven et al. (2006) fits the data best. However, it did underestimate the grass production during winter. Johnson and Thornley (1983) overestimated grass production many times and the model of Brereton overestimated the grass production in the most crucial time of year (week 27 to week 33).

The model of Jouven et al. (2006) was developed to approach grasslands on functional basis (average functional traits of the grassland community) and the structural basis (distinction between vegetative and reproductive; green and dead matter). The model is based on sub-functions: growth functions to estimate grass production, senescence and abscission functions and harvested herbage mass. Total grass production of Jouven's model is based on LINGRA, with additions of other models (Jouven et al. 2006). Senescence and abscission functions and harvested herbage mass calculations are comparable to the calculations made in LINGRA.

2.4.2 Barrett and Laidlaw

Barrett et al. (2005) tested several existing grass growth models to see what model is the best fit compared to the actual data. Models that were tested were existing models of Brereton et al. (1996), Schapendonk et al. (1998) and Johnson and Parsons (1985) or adaptations to the models. Barrett and Laidlaw tested the models in Hurley (Northern Ireland) and Belfast (south east England). The comparison of the outcome of the models at two different location showed that the model of Brereton et al. (1996) predicted the grass growth the best when they were tested at Hurley. However, overall the model of Schapendonk et al. (1998), called LINGRA, and the modified LINGRA with the reproductive phase showed the best fit with the actual data.

2.5 Choice of model for McGraze

Concluding from all the existing models and the evaluations done by both Van den Pol-van Dasselaar et al. (2011) and Barrett et al. (2005), LINGRA is the most reliable model to predict grass production. LINGRA is very reliable due to the fact that it is calibrated European-wide (Bouman et al. 1996; Schapendonk et al. 1998). The northern site of Europe reduced the absolute error with 70% and the southern site of Europe reduced the average absolute error with 58% (Bouman et al. 1996).

From the non- grass production model discussed before, only GrazeIn is usefull for McGraze. The part of GrazeIn that is interesting to use, the total dry matter intake prediction, is discussed in chapter 4.5.4.

3. LINGRA

LINGRA is a dynamic model that predicts grass production of Lolium Perenne. “LINGRA is based on LINTUL (Light INTerception and UtiLisation simulator), which was originally developed for potatoes” (Spitters and Schapendonk 1990). LINTUL-GRASS is adapted into a grass growth prediction model, called LINGRA (Spitters and Schapendonk 1990).

LINGRA integrates the effect of weather conditions on grass production. According to Van der Linden (personal communication, 16 February, 2015), the average weather condition over the last 10 years of a specific country is used in the model to predict the grass production per day for the coming year of that specific country. The grass species that LINGRA uses is Lolium Perenne, since this species is most found in Northwest Europe. Furthermore, LINGRA assumes a standard management practice to decrease the numbers of factors that are influencing the grass production. Standard management practices are an interval of four weeks for mowing in the model, an optimal protection against pest, diseases and weeds and two options for water supply (Bouman et al. 1996):

- Irrigation, which is based on the potential production. Due to irrigation the supply of water and nutrients is fixed and always sufficient. This leads to grass production only determined by changing conditions of solar radiation and temperature.
- Rainfall, which is based on water-limited production. Under these conditions growth can be limited by water shortage and changes in solar radiation and temperature. Besides, soil characteristics become a determining factor as well, since this influences water availability. The only fixed factor is the nitrogen supply, which is always sufficient (Bouman et al. 1996).

3.1 Key elements of the LINGRA

Grass production depends on three main factors: potential growth of the plant, seasonal patterns of growth and environmental variables related to climate conditions and soil type (Jouven et al. 2006). The relations between these factors will be explained.

3.1.1 Potential growth

Potential growth is affected by different sub factors:

- Crop growth rate. Potential growth per day is the product of: photosynthetically active radiation (PAR), the light utilisation efficiency (LUE) and a function of the leaf area index (LAI) which indicates the fraction of intercepted light by the sward (Schapendonk et al. 1998). Where the unit of LAI is m^2 leaf surface/ m^2 ground surface.
    - LUE is affected by three factors: light intensity, temperature and water availability. Where water availability is only a problem for water-limited production. In the potential production method water is always available due to irrigation.
        - Light intensity: At a low intensity, the LUE is high. The LUE declines with more light intensity, since photosynthesis will become saturated.
        - Temperature: Photosynthesis will be activated above 3°C. Between 3-8°C light utilisation will linearly increase and between 8-40°C the utilisation remains constant (Bouman et al. 1996).
        - Water availability: When the uptake of CO_2 is reduced, the efficiency of absorbed light becomes less. A reduced uptake of CO_2 takes place when the stomata are closed, which occurs to prevent dehydration. Transpiration and evaporation are related to dehydration.
- Total actual crop growth is determined by the balance between assimilate demand (sink) and assimilate supply (source) (Bouman et al. 1996)
    - Assimilate demand comes mainly from leaf growth which is crucial for grass production. Leafs determine the amount of light that will be absorbed.
        - Growth of a leaf after cutting is the result of the numbers of tillers that have a node for leaf elongation.
        - Number of tillers is determined by leaf elongation rate and average width of new leaves is a model parameter (Bouman et al. 1996).
        - Newly formed assimilates are divided between the leaves (above-ground biomass) and the roots (below-ground biomass).
    - Assimilate supply has two sources:
        - Fixed amount of assimilates gained by photosynthesis during the day.
        - Reallocated assimilates of stored carbohydrates in the reserve pool.
    - Actual growth rate: Growth only takes place when the supply (photosynthesis plus reallocation from the reserve pool) exceeds or equals the demand function (Bouman et al. 1996).
- Leaf growth: actual leaf growth is derived from the death rate of leaves by senescence and the amount of assimilates available for growth. Relative death rate of leaves is affected by internal shading and by water stress (Spitters and Schapendonk 1990). Senescence does not occur below 10°C (Jouven et al. 2006).
- Tillering rate: Each tiller produces new leaves and in principle each axil of a leaf contains a bud to produce new tillers (Bouman et al. 1996). Light, temperature and stress conditions have an effect on the tillering rate.
    - Relative tillering rate is different in the first week after (periodic) cutting than the period after.

- Tiller death rate is affected by temperature sum (which is the integrated daily average temperature minus 10°C) and by LAI.

3.1.2 Seasonal patterns of growth

- A fixed cutting regime is set in LINGRA: the crop is mown at the beginning of each month starting after spring (re)growth and ending at winter dormancy. However, cutting interval can be changed over time. Cutting leads to a defoliating of grass and defoliating leads to a reset of LAI (Schapendonk et al. 1998).
- Crop development: In *Lolium Perenne*, the crop does not fulfil a natural growth cycle with a vegetative stage, flowering, ripening and death, due to cutting.

3.1.3 Environmental variables

Environmental limitation of growth is the product of nitrogen content (which is fixed in the LINGRA model), a decrease in LUE, photosynthesis activation after winter and water stress (Jouven et al. 2006):

- LUE has a constant value of 1, when PAR is below 5MJ. Above 5MJ (more light), the LUE will decrease. The PAR in the Netherlands is maximum 25MJ.
- Photosynthesis activation starts when more than 10 days in a row the average temperature is above a certain temperature. This activation means automatically a start of the growth of the plant.
- Water stress is the ratio of water reserves (WR) to soil water-holding capacity (WHC) and is depending on several factors:
    - During rainfall more water can be stored when the WHC is high and during evapotranspiration this water is used by the grass.
    - Water can be stored in the rooted depth until field capacity is reached (Bouman et al. 1996).

3.2 Adjustments to LINGRA

Adjustments that should be made in LINGRA or should be taken into account when using LINGRA are listed below.

3.2.1 Soil type

Soil type in LINGRA is defined by parameters. These parameters have different values which are fixed for every soil type. Soil type can be defined into: sandy, loam and clay types (Barrett et al. 2005). The parameters in LINGRA to determine the soil type are listed in table 2. The wilting capacity and field capacity are most varying among soil types according to Van der Linden (personal communication, 27 February, 2015). Table 3 shows the field capacity and wilting point of the three main soil types.

Table 2. Parameters in LINGRA specific for soil type

Parameter	Unit
Drainage rate	mm/day
Maximum root depth	cm
Maximum root growth	cm/day
Air dry water content	fraction
Wilting capacity water content	fraction
Initial water content	fraction
Minimum water content at water logging	fraction
Saturation water content	fraction

Table 3. Field capacity and wilting point per soil type (Cornell University 2010)

Soil type	Field capacity	Wilting point
Sandy soil	15-25%	5-10%
Loam soil	35-45%	10-15%
Clay soil	45-55%	15-20%

3.2.2 Cutting regime

LINGRA uses a fixed cutting regime based on monthly mowing/cutting. Daily grazing is not taken into account in LINGRA. Van der Linden (personal communication, 27 February, 2015) adjusted LINGRA for this McGraze to be used for stocking. Van der Linden adjusted that cows now 'cut the grass' till a minimum of 8cm (2100kg DM/ha). Van der Linden (personal communication, 27 February, 2015) also adjusted LINGRA in such a way cutting and regrowth can take place simultaneously.

3.2.3 Grass species

LINGRA is predicting grass production of a *Lolium Perenne* dominant pasture. However, pastures in the Netherlands consist also of mixtures of other species. More about grass cover is explained in chapter 5.2.4. Parameters that LINGRA uses to indicate the grass species are listed in table 4. For McGraze these parameters are filled in already, but other values could be used for other grass species in LINGRA.

Table 4. Parameters in LINGRA specific for grass species.

Parameter	Unit
Maximum root depth	cm
Atmospheric CO_2 concentration	Ppm
Critical LAI	Fraction
LAI	m^2 leaf surface/ m^2 ground surface
LUE	g DM/ MJ PAR intercepted
Specific leaf area	m^2/g DM
Maximum nitrogen content	%
Actual nitrogen content	%
Base death rate	Fraction
Base temperature grass specific	°C

3.2.4 Weather forecast

Weather has a major effect on grass production (Johnson and Parsons 1985). LINGRA is predicting grass production, based on weather conditions of the past decade (Meehl et al. 2000). However, weather is highly variable and continues to change dramatically in the future (Barrow and Hulme 2014). The earth surface temperatures are predicted to continuously increase and have great effect on global hydrological and energy cycles changes (Beniston et al. 2007). Therefore, the average weather conditions used in LINGRA are not accurate to predict real time grass production. Thus, the weather forecast of a whole week, preferably a week average, should be introduced in LINGRA for a better estimation of the future trends of weather and the effect on grass growth.

Basic weather forecasts as the ones that can be found on the website of Koninklijk Nederlands Meteorologisch Instituut (2015)(Table 5) or on WeerOnline, the website of Meteovista (2015)(Figure 6) use different measurements and units as the ones LINGRA is able to process. Therefore, it is necessary that McGraze converts these values into usable ones for LINGRA. Table 6 shows how the weather characteristics should be adjusted.

Table 5. Example of weather forecast from Koninklijk Nederlands Meteorologisch Instituut (2015) for 27-02-2015

	Sat	Sun	Mon	Tue	Wed	Thu
Sunshine (%)	50	30	30	30	30	50
Rainfall probability (%)	40	90	80	70	60	80
Amount of rainfall (mm)	1	5/7	2/6	2/4	1/3	1/2
Minimum temperature (°C)	0	4/5	2/3	1/2	0/1	-2/1
Noon temperature (°C)	7	8/9	6/7	5/6	6	6/7
Wind direction	ZW	ZW	W	ZW	W	N
Windforce (bft)	5	5	5	4	4	4


Weather forecast for Wageningen

48 hours | 5 days | 14 days | Webcams (1) | Climate

The weather forecast for **Wageningen** in the next 14 days

	Fri 27 Feb	Sat 28 Feb	Sun 01 Mar	Mon 02 Mar	Tue 03 Mar	Wed 04 Mar	Thu 05 Mar	Fri 06 Mar	Sat 07 Mar	Sun 08 Mar	Mon 09 Mar	Tue 10 Mar	Wed 11 Mar	Thu 12 Mar
Min (°C)	4°	-1°	7°	4°	0°	0°	0°	0°	-1°	2°	3°	4°	4°	2°
Max (°C)	7°	9°	10°	8°	7°	7°	7°	7°	7°	8°	10°	10°	10°	11°
Wind Bft	4 /	5 /	5 /	4 /	4 /	4 /	4 /	3 /	3 /	4 /	3 /	4 /	4 /	4 /
Precip. (%)	10%	40%	90%	90%	85%	85%	60%	60%	55%	60%	60%	60%	60%	45%
Precip. (mm)	5.5 mm	0.1 mm	6 mm	5 mm	3 mm	3.5 mm	1 mm	1.5 mm	0.7 mm	2 mm	1.5 mm	3 mm	2 mm	0.8 mm
Ratings	7	6	5	5	5	5	6	7	7	4	6	4	6	6

Last update 27 February 12:52

Figure 6. Example of weather forecast fromMeteovista (2015).

Table 6. Conversions needed to use McGraze's weather forecast characteristics in LINGRA

MCGraze		LINGRA	
	Unit		Unit
Date	yyyy-mm-dd	Year	yyyy
		Day of year	Day of year1
Temperature	°C	Min. temp	°C
		Max. temp	
Rainfall	mm	Daily rainfall	mm/day
Windforce	Bft	Average wind speed	m/s
Sunlight	%	Solar radiation	kJ/m2/day
Relative humidity	%	Water vapour pressure	kPa

[1] 0= 1st of January … 365/366=31st December

4. Stocking related processes

In order to complete McGraze, stocking related processes need to be implemented next to the adjusted LINGRA. This chapter contains several factors that should be considered for McGraze.

4.1 Grass height measurement

The choice of method to measure grass height generally depends on the type of sward being studied and on the experience of the people measuring it (Hodgson 1993).

The sward stick (HFRO) can be used to measure the architecture and heterogeneity within swards (Dennis et al. 1997; Milsom et al. 2000) and aspects of herbivory, agriculture and grassland productivity (Wright and Whyte 1989; Maxwell et al. 1994; Carrere et al. 1997).

The sward stick method (HRFO) involves a 45cm metal ruler with 0,5cm gradations, with a sleeve supporting a projecting 2 × 1cm piece of clear perspex; the ruler is held vertically, the sleeve lowered until the perspex touches the first piece of green non-flowering grass and the height read on the rule (Barthram 1986). The direct measurement method involves placing a card or hand lightly on the grass at the level below which about 80% of the grass is estimated by eye to be growing (thus ignoring occasional tall stalks), then reading this height on a ruler. The drop disc method (Holmes 1974) involves letting a disc with a central slot drop down a vertically held ruler, and measuring the height above ground where it comes to rest. Standard discs are 30cm ($0.07m^2$) in diameter, weigh 200g ($2.85kg/m^2$) and are dropped from a 1m height. Another method used by Lantinga (1985) in the Netherlands is the tempex disc. Comparing the tempex disc with the sward stick, the grass height will be underestimated by 2cm due to compression by the disc. 't Mannetje and Jones (2000) also concluded that the drop disc and HFRO sward stick are the best methods for frequent use on *Lolium Perenne* and *Trifolium Repens* pastures. Visual estimation by farmers can be very accurate as well as. The standard deviation of visual estimation compared with real measurement declined from about 0.20 to 0.12 when herbage mass increased from about 1000 to 3000 kg DM/h, which indicates it is an accurate way of herbage mass estimation (O'Donovan et al. 2002).

The sward stick however consistently gave higher absolute values than either of the other methods. This can lead to major misapplications of the measured grass height. Therefore some equations to calculate the correct height can be found below (Stewart et al. 2001):

1. Drop disc = 0,72 * direct method + 2.1
2. HFRO sward stick = 1,.25 * direct method + 1.3
3. HFRO sward stick = 1,73 * drop disc + 0.2

Advice: Use the sward stick or tempex disc in combination with common sense. Visual estimation by farmers can be very accurate as well.

4.2 Optimal grass height

For different stocking methods different optimal grass heights are applied, because of optimal grass production and grass intake by cows.
According to Hodgson (1981) the rate of grass intake by cows increases with increasing grass height and the rate of grass intake has a major effect on total daily feed intake of cows. The maximum grass intake for continuous stocking is achieved at a sward height of 8-9cm, measured with a sward stick according to Le Du et al. (1979). Maintaining low levels of pre-grazing herbage mass (1150kg DM/ha) reduces grass DM production. At a system level, grazing low herbage mass pastures (1150kg DM/ha), resulted in greater pasture deficits at grazing and reduced the amount of silage for conservation for winter feeding, without an increase in milk output per cow or per hectare (Wims, Delaby, Boland, & O'Donovan, 2014). Wims et al. (2014) also suggest that maintaining low herbage mass pastures cannot handle increasing stocking rate and kg of milk per hectare. Concluding, adapting the practise of grazing low herbage mass pastures is not a suitable management strategy to reach the optimal grass production from *Lolium Perenne* dominant pastures (Wims et al., 2014).
Wright and Whyte (1989) concluded that for maximum cow performance on continuously stocked pastures, sward height (measured with sward stick) should be maintained at no more than 8 cm in spring and early summer to avoid un-grazed material and flower stem development. In general flower stem development will decrease grass production, because grass will enter the reproductive state instead of remaining in the vegetative state (Wright and Whyte 1989). Flower stem will start developing at a grass height of 8cm. In late summer and autumn grass is more developed, flower stem development will start at grass heights of 9-10cm so

the sward height can be increased slightly to 9-10cm. These heights, both the 8 and 9-10cm, will allow more efficient utilisation of grass (due to less un-grazed parts) and higher grass production in comparison with short swards of around 4cm(Wright and Whyte 1989). The reduction in performance at lower grass heights are caused by a reduction in grass intake (Wright & Russel, 1987). Lantinga (1985) found that optimal grass height is 7-8 cm, due to optimal grass growth. This corresponds with 2100 to 2500 kg DM/ha above ground (Figure 7). In this case sward height was measured using a tempex disc with a diameter of 50cm and a weight of 150 g. This method compared to the sward stick method will lead to an overestimation of the grass height. So the 9-10cm of the sward stick is in line with the 7-8cm of the tempex disc.

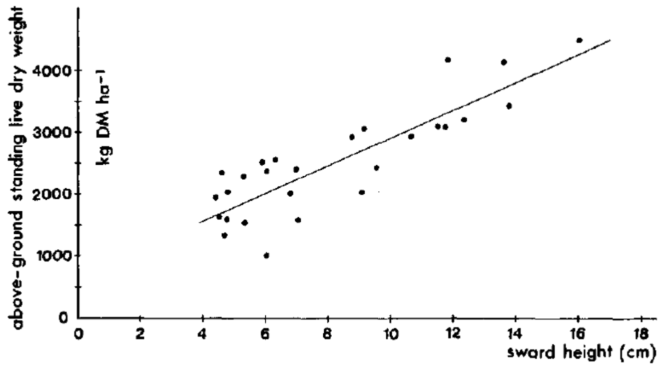


Figure 7. Relation between sward height and above-ground standing live dry matter (kg DM/ha) (Lantinga 1985)

Advice: McGraze should take into account that grass height in spring should be 8cm and later in summer and autumn it can be increased up to 10cm measured with sward stick. When measured with tempex disc, 7cm in spring and 8-9cm in later growing season are optimal heights. This corresponds with 2100kg DM/ha in spring and 2500kg DM/ha later in the growing season.

4.3 Grass quality

It is important to know the quantitative estimates of dietary requirements of a cow for energy, protein and minerals as they are necessary to calculate the amount of feed needed for a specific level of milk production. The nutrient requirement for milk production depends on cow performance. The average annual milk production for a conventional farm is approximately 9000kg (ARC 1980; Bargo et al. 2003). In this chapter the average requirements for maintenance and milk production are collected and summed up according to the application rules of the ARC (1980). Next to that this chapter also provides information about grass quality (i.e. nutrient composition) throughout the stocking season.

4.3.1 Nutrient requirements of dairy cows

First of all, the average energy cow requirement for maintenance and milk production of 9000kg/year/cow is 140MJ/day of metabolisable energy (ME) which is equivalent to approximately 13kg DM/day of pasture intake to satisfy the energy requirements (ARC 1980). Grasses with high concentration of water-soluble carbohydrates (WSC) are more palatable, increase grass intake and could increase the utilization of grass protein to milk production (Taweel et al. 2005). About proteins, the minimum DVE (darm verteerbaar eiwit), true protein digested in the intestine, required for milk production for lactating cows is 1.37kg/day assuming the Netherlands average milk protein content of 3.3% with a milk yield of 25kg/day (Remmelink 2014). In general, grass provides enough protein supply for milk production in all stocking seasons (E. Lantinga and G. van de Ven, personal communication, 25 February, 2015). Cows tend to select for grass with high protein content. For example, Dalley et al. (1999) observed a 30% increase in DM intake in a *Lolium Perenne* strain having 40% higher CP content compared to another strain. This suggests that providing the cows with grass of high protein content increases DM intake of grass, leading to an increased milk production (Dalley et al. 1999). This suggests that providing the cows with grass of high protein content increases DM intake of grass, leading to an increased milk production. Macro-elements (Calcium (Ca), sulfur (S), magnesium (Mg), potassium (K) and micro-elements Cobalt (Co), Selenium (Se) and Iodine (I) are essential for milk production and in case of deficiency, it can cause severe decline in milk yield amongst other symptoms (Schroeder, 2009; C. Stockdale, 1999)(Table7).

Table 7. Estimates of mineral concentration required for cows (ARC, 1980)

Minerals	Concentration required for cows[1]
Ca	3.9g/kg DM
S	3.5g/kg DM
Mg	2.0g/kg DM
K	5.4g/kg DM
Co	0.08mg/kg DM
Se	0.05mg/kg DM
I	0.5mg/kg DM

[1] Assuming the target milk yield is 9000 kg/year/cow and the DM intake is 15 kg/day

4.3.2 Seasonal variation of grass quality

Although nutrient requirements for cows are relatively constant throughout the year, nutrient content of the grass varies between seasons. Having an estimate of the nutrient requirements and knowing the nutrients supplied by consumed grass can help farmers calculate how much additional feed should be fed in order to maintain a certain milk yield (Delagarde et al. 2011). Seasonal variation in nutrient content was investigated in *Lolium Perenne* dominant pastures. To exemplify, the WSC shows significant variation between seasons due to the changes in light intensity and temperature. Total WSC content in *Lolium Perenne* increases with increasing light intensity and decreases with increasing temperature (Metson and Saunders 1978). WSC content are lowest in early autumn (115g/kg DM) and highest in summer (350g/kg DM) (Fulkerson and Donaghy 2001). In general, minerals in the pasture are highest during the late spring and summer (Metson & Saunders, 1978a; Roberts, 1987). For example, Ca in pasture is highest (4.3g/kg DM) from the summer and lowest (1.0g/kg DM) during late autumn; the Mg and K content is highest (3.2g/kg DM and 4.5g/kg DM, respectively) in summer and autumn in comparison to spring and content of S in pasture is relatively constant during the whole year (3.5g/kg DM)(Metson & Saunders, 1978a, 1978b; C. Stockdale, 1999; C. R. Stockdale, 1999).

Advice: As pointed out, the grass quality varies through the season. The advice is to assign a cow nutritionists to calculate different diets for the different seasons. This can be done by measuring the grass quality throughout the stocking season and use this as an input for the additional feed.

4.4 Effect of stocking on grass growth

This chapter gives an overview in what ways cows affect grass growth in pasture.

4.4.1 Trampling

Trampling is the negative effect of the walking cows on grass growth. This is usually not relevant for MCS, because of the low stocking density. However, it should be mentioned that a lot of environmental factors influence the resistance of the grass to trampling, for instance the amount of moisture in the soil. Plant communities are less tolerant to trampling when the ground is wet than when it is dry (Edmond, 1962).

4.4.2 Urine and dung spots

According to GrazeVision (chapter 2.2) cows have a preference of grazing area (Zom and Holshof 2011):

1. New regrowth of previously cut or graze grass

2. Clean residual herbage from previous grazing
3. Grass on old urine spots rejected during previous grazing
4. Tall patches around old dung spots

Manure deposition may lead to grass loss because cows will not eat the grass.

4.4.3 Disturbed versus undisturbed grass growth

In addition to the effect trampling on grass growth, the possible difference in *Lolium Perenne* growth rate between disturbed growth (pasture is grazed) and undisturbed growth (no grazing) is studied. The reason for this study is that LINGRA does not take the effect of grazing on grass growth into account. LINGRA assumes that the pasture gets mowed on a regular interval with no stocking in between. Maintaining a grass height of 8-10cm denotes that some old leaves will remain in the pasture without being replaced by new ones. Having old leaves in the pasture lowers grass production due to the old leaves' low photosynthetic capacity compared to the new ones (Trlica 2013). Therefore, Under MCS, disturbed grass growth will occur and leads to a lower grass production (E. Lantinga; personal communication, 27 February, 2015).

Advice: When the soil is too wet the stocking rate should be lower and/or the grazing time should be reduced up to no grazing at all. This should be taken into account in the MCS management. Urine and dung spots and disturbed grass growth have a negative effect on grass production. Grass production estimated by LINGRA should be multiplied by 0.8 to take these grass losses into account (E. Lantinga; personal communication, 27 February, 2015).

4.5 Grass intake

The amount of grass consumed by cows is influenced by the time spent on grazing, the biting rate and the amount of intake in each bite (Holmes, 1980). High yielding cows require 500 to 700min/day to graze and have biting rates up to 65 bites/min (Holmes, 1980). Biting rate and bite mass are influenced by grass height, grass density and the bodyweight of the cow.

4.5.1 Grazing time

Amount of time spend on grazing is usually influenced by the ratio of grass and additional feeding, grass quality and farmer's decision. The farmer makes the decision of how long cows will be stocked. However, there is a big difference between stocking and actual grazing. The behaviour of cows in the paddock consists of grazing, resting and ruminating (Stobbs 1970). There are two main grazing periods during the day: one in the morning (start between 6 and 7am) and one in the afternoon (start around 4pm) (Chilibroste et al. 1997). Figure 8 shows the typical behaviour of cows in the paddock for one day and it shows that grass height has an effect on the grazing behaviour of cows. Holmes (1980) concluded that cows grazing a very short sward and offered additional feed decreased their grazing time compared with cows on a longer sward offered the same amount of additional feed. Cows reduce their grazing time when only stem material was left in the grass (Holmes 1980).

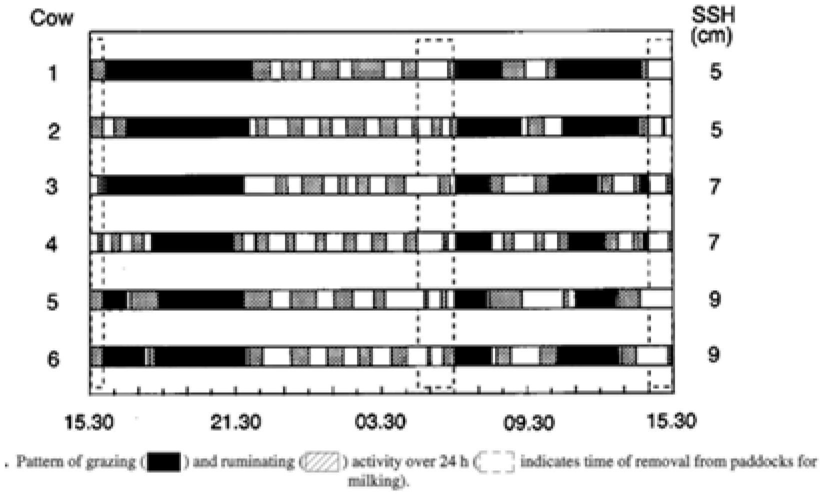


Figure 8. The typical temporal pattern of grazing by cows over 1 day and the effect of grass height on grazing behaviour (Gibb et al. 1997).

4.5.2 Biting rate

Biting rate is influenced by the time required to search for each bite and the time required processing the bite (Muller, 2003). The time severing a bite is relatively fixed; biting rate generally varies between 45-65 bites/min (Muller, 2003). However, biting rate also may be influenced by intake per bite, tending to increase with reductions in bite size. Cows stocked on temperate pastures have a maximum of approximately 40.000 bites per day (Muller, 2003). Chewing time increases linearly with bite mass. The time per bite increases with bite mass because the numbers of movements decrease with an increase in chews per bite (Muller, 2003).

4.5.3 Bite mass

Bite mass is influenced by bite volume, grass height and grass density. The bite volume is influenced by the size of bite dimension and bite depth. Bite depth is limited by body weight (BW) without the effect of grass height (Illius & Gordon, 1987). When the weight of animals is variable in a small range, bite mass will scale with $BW^{0.75}$ when grass height is non-limiting, but scale with $BW^{0.36}$ on short grass (lower than 5.5cm) (Illius & Gordon, 1987). Since the grass height is kept relatively high (8-10cm), bite volume is influenced by sward height and sward density (Figure 9).

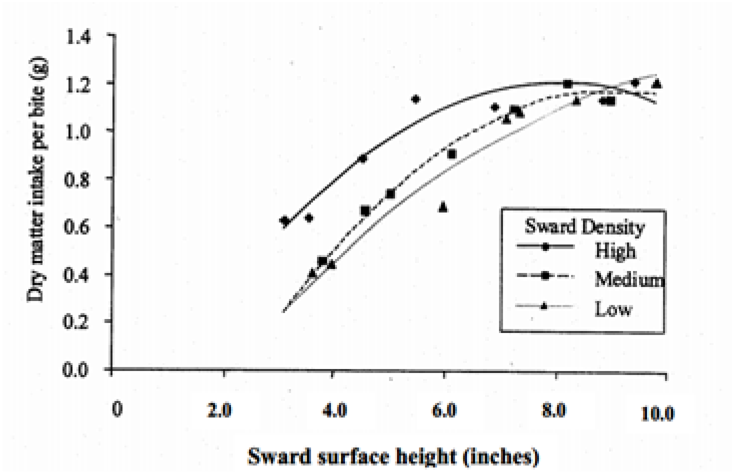


Figure 9. Effect of sward height (inches; 4 inch is 10 cm) and sward density on bite mass at different sward densities (Hopkins, 2000).

4.5.4 Relationship between sward availability and time at the paddock

GrazeIn, described in chapter 2.1.3, is a model that predicts total DM intake of cows under rotational or continuous stocking systems (Delagarde et al. 2011). The total DM intake is based on the interaction between herbage intake and additional feed intake. Herbage intake prediction under continuous stocking is interesting to use in McGraze. Under continuously stocking, herbage intake at grazing (HI_G; kg DM/day) is calculated based on two parameters: herbage intake based on sward availability (HI_{G1}) and herbage intake based on the time spend at paddock (HI_{G2}). One of them is always a limiting factor, which means that HI_G is the same as the lowest value of the two parameters (Delagarde et al. 2011). Table 8 shows all the variables which determine the total DM intake.

Table 8 Characteristics used in GrazeIn to predict total dry matter intake (Delagarde et al. 2011).

Name	Unit	Description
Animal variables		
IC	FU/ cow	Mean intake capacity of the herd
HI_v	kg DM/day	Voluntary herbage intake
HI_G	kg DM/day	Herbage intake at grazing
HI_{G1}	kg DM/day	Herbage intake at grazing (without time at pasture limitation)
HI_{G2}	kg DM/day	Herbage intake at grazing (without herbage availability limitation)
HI_{R-SSH}	kg DM/day	Relative herbage intake limited by sward surface heights
HI_{TAP}	kg DM/day	Relative herbage intake limited by daily time at pasture
Diet variables		
F_i	kg DM/day	Intake of forage
C_j	kg DM/day	Intake of concentrate
FV_{FI}	FU/ kg DM	Fill value of forage
FV_{Cj}	FU/ kg DM	Fill value of concentrate
FV	FU/ kg DM	Fill value of total feed supplied
Management variables		
SSH	cm	sward surface height
TAP	h/day	Time at pasture

HI_{G1} is calculated from the voluntary grass intake (HI_v) and relative intake limited by sward availability (HI_{R-SSH}). Voluntary grass intake is based on the intake capacity (IC), the intake of forage (F_i), the fill value of forage (FV_{Fi}), the intake of concentrate (C_j), the fill value of concentrate (FV_{Cj}) and the fill value of the total feed (FV) (Delagarde et al. 2011; Faverdin et al. 2011). HI_{R-SSH} is based on several correction factors and the sward surface height (Delagarde et al. 2011). The relationship between HI_{R-SSH} and sward surface height is shown in figure 11.

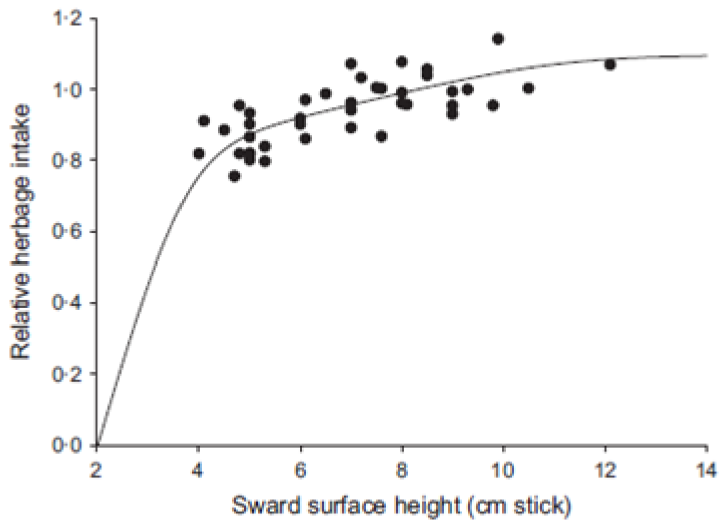


Figure 11. The relationship between sward surface height and the relative grass intake for continuously stocked cattle (Delagarde et al. 2011)

HI_{G2} is calculated from the IC, relative herbage intake limited by daily time at pasture (HI_{TAP}), $HI_{R\text{-}SSH}$, and the FV, when the stocking time per day is more than 20 hour. On the other hand, when stocking time per day is less than twenty hours, HI_{G2} is calculated from the IC, HI_{TAP}, and the FV. HI_{TAP} is based on time at paddock (TAP), sward surface height (SSH) and several correction factors (Delagarde et al. 2011). Figure 12 shows the relationship between TAP and HI_{TAP} and several SSH. It is assumed that four hours per day are spent on milking, so if TAP is higher than twenty hours, then HI_{TAP} is equal to one (Delagarde et al. 2011).

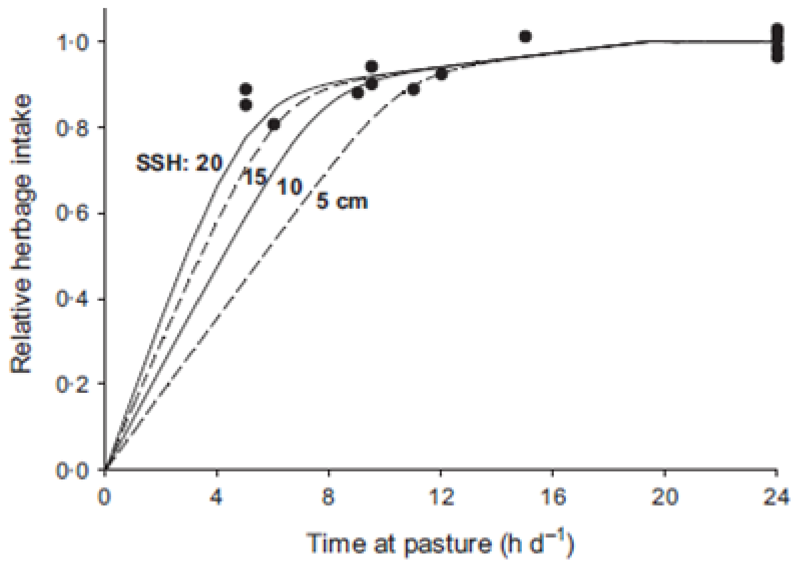


Figure 12. Relationship between daily time at pasture and relative herbage intake from grazing ruminants. Curves: intra-experiment fitted model for different sward surface heights (SSH) (Delagarde et al. 2011)

Maximum hourly intake rate is 50g DM/min or 3kg DM/hour (Delagarde et al. 2011). A higher intake rate (intake rate of 4kg DM/hour) of *Lolium Perenne* is possible, but only during the first hour a cow spends in an undefoliated paddock with a sward surface height of 18-20cm (Mayne et al. 1997). Besides sward surface height, sward density (kg/m^2) has an influence on DM intake rate of cows (Figure 13). This figure shows an average grass intake rate of 2.5kg DM/hour which is achieved by a pre-grazing sward height of 9, 11.5 and 12.5cm with a high, medium and low sward density respectively (Mayne et al. 1997).

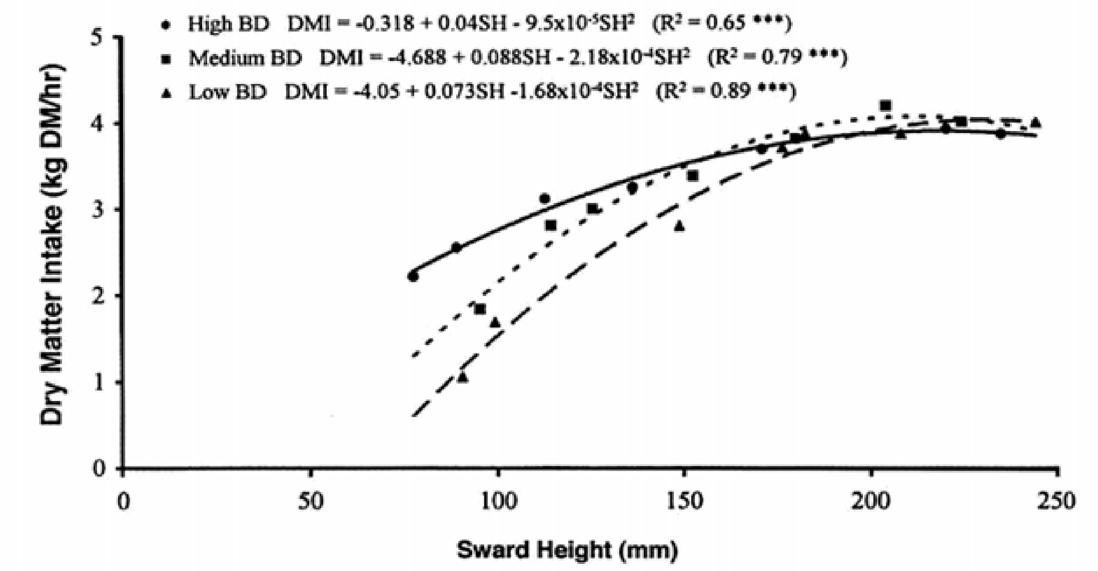


Figure 13. The effect of sward surface height (SH) and bulk density (BD) on dry matter intake (Mayne et al. 1997)

Advice: Grass intake is depending on a lot of factors: actual grazing time, biting rate, bite mass, sward availability, sward height and sward density. Most of these factors are not measurable by farmers or will take too much time. Therefore, we advise to use a fixed number for grass intake. The advice is to use the grass intake rate of 2.5kg DM/hour in McGraze.

5. McGraze

It is very important to keep the interface of the management tool and McGraze user friendly and make it possible to fill in all required parameters (Barrett and Laidlaw 2005). Barrett and Laidlaw (2005) described the perfect support tool as: "*…complex, all encompassing, yet robust and simple to use…*". Further the system should allow a necessary degree of data manipulation and, obviously, provides the user with all needed output information (Barrett and Laidlaw 2005).

5.1 Model

In order to integrate the before mentioned factors (chapter 2, 3 and 4), a concept for McGraze is created and an overview of the system is shown in figure 12 On the right side (what the farmer sees), what the farmer sees is illustrated and contains the inputs that need to be filled in by the farmer and the available outputs for the farmer. The left side (background processes and decisions) provides an overview of all the processes that are needed to obtain the given inputs into the needed outputs (inputs and outputs are explained in table 8. Since McGraze covers the complete system related to MCS, it includes a grass growth model that is linked to grass intake parameters (Barrett and Laidlaw 2005). As explained before, the used grass production model included in McGraze is LINGRA. LINGRA is combined with all the stocking related processes in order for McGraze to calculate the outputs for the farmer.

The system is very easy to use, since the farmer only needs to fill in all the yellow blocks at the beginning of every week. Basically, all the weather condition can be found on the websites of meteorological organisations, free of charge. The herbage mass available at the beginning of the week can be measured by the farmer himself. The farmer can also fill in the paddock size, number of cows in the herd, the soil type of the paddock and the total kg of DM feed as formulated in the diet. On the background, McGraze estimates the two needed outputs by making calculations with all the inputs. The system provides the farmer with the estimated hours that the cows can be stocked daily, for the next seven days. The other output available for the farmer is the amount of kg DM additional feed. The combination of these outputs make that the grass will meet the height requirements for MCS.

Since McGraze is dependent on weather conditions, the predictive power of the system is mostly limited by the reliability of weather forecasts (Barrett and Laidlaw 2005). Since weather conditions, and thus weather forecast may change a lot during the week, the farmer is free to run the model as many times desired. However, this system works the best when used only once a week, since in most of the cases the farmer does not want to change stocking time per day to rapidly and/or often (chapter 5.2.3). In table 9 all the inputs and outputs are explained as shown in figure 14.

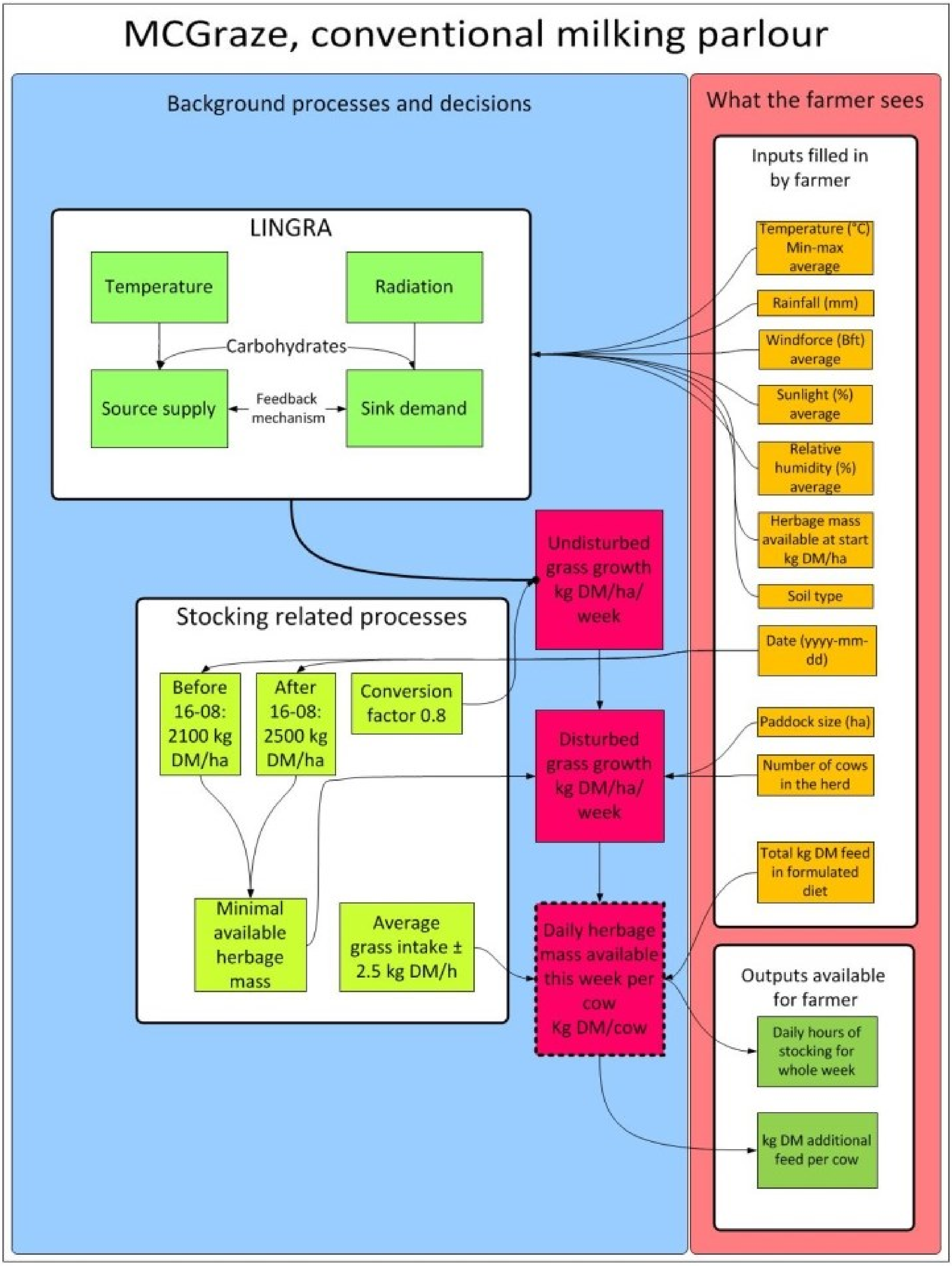


Figure 14. Flowchart of McGraze

Table 9. Inputs and outputs of McGraze.

#	Input farmer	Unit	Input for
1	Date	yyyy-mm-dd	LINGRA
2	Temperature	° C	LINGRA
3	Rainfall	mm	LINGRA
4	Wind force	Bft	LINGRA
5	Sunlight	%	LINGRA
6	Relative humidity	%	LINGRA
7	Herbage mass available at start	kg DM/ha	LINGRA
8	Paddock size	ha	Stocking related processes
9	Number of cows in the herd	#	Stocking related processes
10	Total feed in formulated diet	kg DM	Stocking related processes
11	Soil type	option	LINGRA
#	**Input background process**	**Unit**	**Input for**
12	Average grass intake	2.5 kg DM/hour	Daily hours of grazing
13	Minimal available herbage mass	2100 or 2500 kg DM/ha	Grass available per cow
14	Conversion factor	0.8	Disturbed grass growth
#	**Output background process**	**Unit**	**Equation**
15	Undisturbed grass growth	kg DM/ha/week	LINGRA
16	Disturbed grass growth	kg DM/ha/week	Conversion factor * undisturbed grass growth
17	Daily herbage mass available this week per cow	kg DM/day/cow	Disturbed grass growth + herbage mass available at start – minimum available herbage mass * paddock size / number of cows / 7
#	**Output farmer**	**Unit**	**Equation**
18	Daily hours of stocking for whole week	hours	Daily herbage mass available this week per cow / Average grass intake
19	Kg DM additional feed/cow	kg DM/cow	Total kg DM feed in formulated diet – Grass available this week per cow

Inputs:

1. Date
   Fill in date
2. Temperature
   Fill in average min and max temperatures
3. Rainfall
   Fill total mm of rainfall for the week, including all the applied water via irrigation.
4. Wind force
   Fill in average wind force for the week
5. Sunlight

Fill in average percentage of sunlight for the week

6. Relative humidity

   Fill in average relative humidity for the week
7. Herbage mass available at start

   Fill in measured herbage mass of the paddock
8. Paddock size

   Fill in total amount of hectares which will be stocked
9. Number of cows in the herd

   Fill in total number of cows that will be stocked
10. Total feed in formulated diet

    Fill in total kg DM of feed needed per cow per day from formulated diet. This could differ throughout the season. Due to seasonal variation in grass quality (chapter 4.3) different diets are advised for the additional feed.
11. Soil type

    Choose soil type: sandy soil, loamy soil or clay soil (chapter 3.2.1).
12. Average grass intake

    Average grass intake is influenced by a lot of factors. For this model we decided to use an average of 2.5kg DM per hour (chapter 4.5).
13. Minimum available herbage mass

    Minimum available herbage mass related to the optimal grass height (chapter 4.2) differs per season. 2100kg DM/ha for spring and early summer and 2500kg DM/ha for late summer and autumn. One of the values will be used according to the date.
14. Conversion factor

    A conversion factor to correct for grass loss due to grazing which LINGRA does not take into account (chapter 4.4).

Outputs:

15. Undisturbed grass growth

    Output from the adjusted LINGRA model (chapter 3)
16. Disturbed grass growth

    Undisturbed grass growth corrected for grass loss due to grazing with the conversion factor (chapter 4.4)
17. Daily herbage mass available this week per cow

    Output for the model which indicates how much grass is available for the cows in coming week. This will be an output for farmers using an automatic milking system (AMS).

    *Daily herbage mass available this week per cow=(((Disturbed grass growth + Herbage mass available at start – minimum available herbage mass) * paddock size)/ number of cows)/ 7*
18. Daily hours of stocking for the whole week

    Output of the model to the farmer.

    Daily herbage mass available this week per cow / average grass intake.
19. Kg DM additional feed/cow

    Total kg DM feed in formulated diet – Daily herbage mass available this week per cow.

5.2 Management

When using this McGraze, other management issues have to be considered as well for a good management of MCS. For example, the rotation between the paddocks, best species of grass for MCS and decisions rules between different milking systems.

5.2.1 Advice for rotation management

McGraze is used for the pasture which is grazed at that time. While grazing one paddock, the two other paddocks also need to be managed. In order to do so there are some decisions rules for the farmer (G.-J. Nijland, personal communication, 27 January, 2015):

- In the resting period, between two grazing periods, the paddocks need to be mowed to obtain a flat and homogeneous sward height. Immediately after the cows are moved to another paddock, the paddock has to be mowed. However, when a little amount of grass pollen is left, this mowing can be omitted.
- Application of manure or fertilizer should happen as soon as possible after mowing for flattening or mowing for ensiling. In this way, the grass is most palatable.
- After grazing the grass must regrowth for at least three weeks. Then grass can be mowed for ensiling and finally the grass needs about two/three weeks of regrowth. After that the cows can graze the paddock again. A cycle is obtained so that every paddock can be grazed for three weeks.
- Pasture should not be grazed in case of excessive rainfall to prevent trampling.

5.2.3 Automatic milking systems

In stocking management, the choice of milking system has a big influence. More than half of the farmers in the Netherlands still use grazing after introduction of an automatic milking system (AMS) and this proves that it can be combined successfully. This is a positive result compared to the sometimes negative attitude of farmers toward grazing in combination with AMS (van Dooren 2002).

Milking in a conventional milking system means that the stocking period is well defined between the milking sessions and variable in time, the use of AMS demands free cow traffic between the barn and the paddock. As a result, stocking time differs from cow to cow where every cow used to have the same time in the paddock. Being in the paddock does not mean grazing. This has to do with the amount spent on resting versus grazing (chapter 4.5). Furthermore, giving cows the opportunity to graze during the summer season may reduce how frequent AMS is visited (van Dooren, 2002). Stocking rhythm is very important for cows in an AMS in order to keep the milk frequency steady. Farmers using an AMS should keep stocking hours constant to make sure the cows come to the AMS (van Dooren, 2002). This is in contrast with conventional milking, where the cows have to be fetched and milked either way (van Dooren, 2002). For the farmer wanting to combine AMS and stocking, it is important to localize the stocking area as close to the barn as possible and to observe cow behaviour to ensure that nutrient intake of animals is sufficient to maintain milk production level (Spörndly & Wredle, 2004). AMS has some restrictions and decision rules in order to obtain a good milk production, whereas for conventional milking the farmer is more flexible.

Advice: The hours of stocking will be a fixed number of hours and the output of the model for the farmer should be daily herbage mass available coming week per cow and amount of additional feed per cow (Figure 15). The rhythm should be adjusted where grass intake can be controlled by provided additional feed.

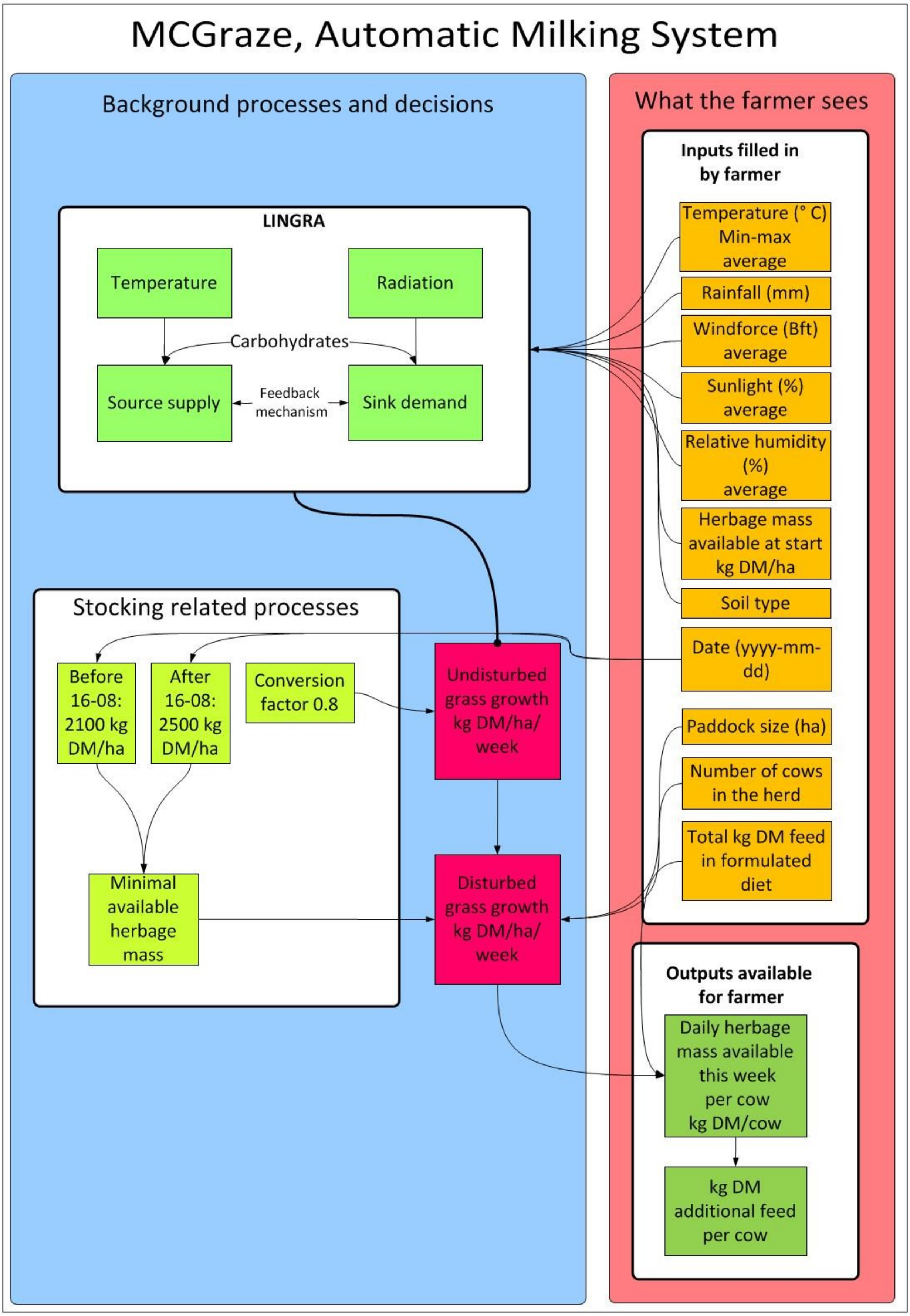


Figure 15. Flowchart of McGraze for Automatic Milking System (AMS).

5.2.4 Grass cover

In practice farmers never have a 100% *Lolium Perenne* pasture. Other grasses, weed and herbs will invade the pasture. This will influence the grass production and quality. In a standard manner, that means optimally provided with nutrients and optimally protected against yield limiting factors such as pests, diseases and weed, LINGRA can predict the grass growth of this *Lolium Perenne* dominant pasture (Bouman et al. 1996).

Advice: When the pasture is invaded by weeds or other grasses the pasture should be over- or re-seeded with Lolium Perenne.

5.2.5 Disclaimer

In McGraze, farmers weekly measure the grass height in order to determine the herbage mass per hectare in addition to ensuring that the grass height is within the 8-10cm range for optimal grass production. However, it is possible that grass height drops below the 8cm in the middle of the week due to unforeseen circumstances that cannot be predicted by McGraze. This results in overgrazing of the paddock, a shortage of additional feed for the week and a grass height below the recommended height of MCS.

Advice: Farmers should watch grass height more than once per week as a precaution to ensure grass height will not drop below the 8 cm. If the grass height drops below 8cm, the daily hours of grazing should be adjusted accordingly

6. Future perspective

In order to make it into a real working program, this documentation should be handed to a programmer or model experts. This person can put all the research into practice by changing LINGRA and by adding the stocking related processes into McGraze. Eventually McGraze should be validated by testing it in practice. In the future, more advanced techniques can be applied to the model. For example, the weather changes in the next few days can be predicted by linking it to real-time weather satellites. Available herbage mass can be estimated and grass species can be identified by the help of the images of geostationary satellites. Bite rate and the effect of trampling on grass growth can also be measured by GPS collar. Furthermore, bite mass and ratio resting/grazing can be added to McGraze to have an accurate number for average grass intake (Figure 16). Using these new techniques, McGraze can estimate the grass production and grass intake of the cows more accurate. Finally McGraze could be extended with grass quality parameters and cow's requirements for accurate additional feeding.

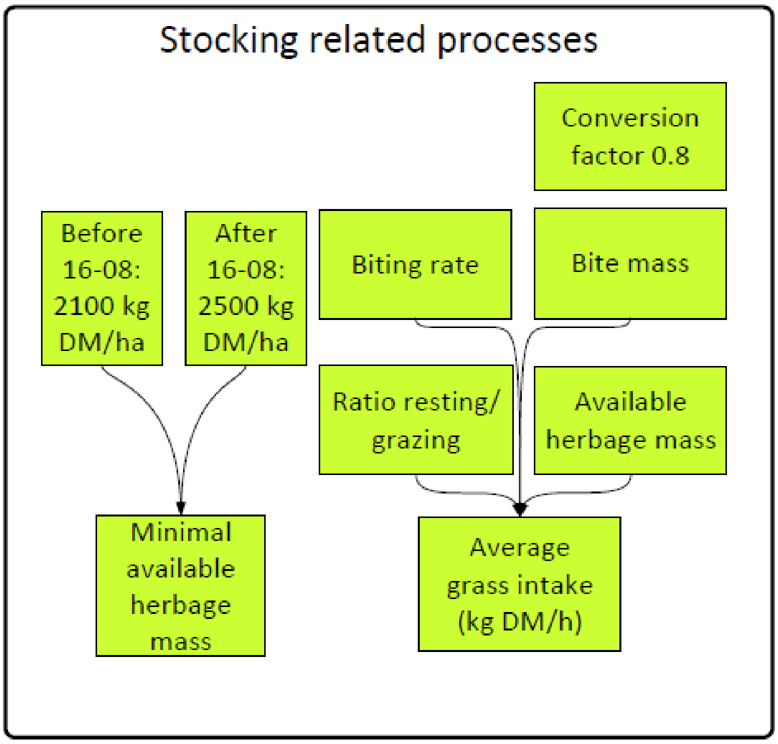


Figure 16. Future stocking related processes which can be included in McGraze

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8. References

't Mannetje, L., and R. Jones. 2000. Measuring biomass of grassland vegetation. *Field and laboratory methods for grassland and animal production research*: 151-177.

ARC. 1980. *The Nutrient requirements of ruminant livestock: technical review*. UK: Commonwealth Agricultural Bureaux.

Bargo, F., L. D. Muller, E. S. Kolver, and J. E. Delahoy. 2003. Invited Review: Production and Digestion of Supplemented Dairy Cows on Pasture. *Journal of Dairy Science* 86 (1): 1-42. http://dx.doi.org/http://dx.doi.org/10.3168/jds.S0022-0302(03)73581-4.

Barrett, P. D., and A. S. Laidlaw. 2005. Grass growth modelling: to increase understanding and aid decision making on-farm. In *Utilisation of grazed grass in temperate animal systems*, edited by J.J. Murphy. Wageningen: Wageningen Academic Publishers.

Barrett, P. D., A. S. Laidlaw, and C. S. Mayne. 2005. GrazeGro: a European herbage growth model to predict pasture production in perennial ryegrass swards for decision support. *European Journal of Agronomy* 23 (1): 37-56. http://dx.doi.org/http://dx.doi.org/10.1016/j.eja.2004.09.006.

Barrow, E., and M. Hulme. 2014. *Climates of the British Isles: present, past and future*: Routledge.

Barthram, G. T. 1986. xperimental techniques – the HFRO sward stick. Biennial Report of the Hill Farming. In *Biennial Report of the Hill Farming Research Organisation 1984-85*, edited by M.M. Alcock. Penicuik, Midlothian, UK: Hill Farming Research Organisation.

Baudracco, J., N. Lopez-Villalobos, C. W. Holmes, E. A. Comeron, K. A. MacDonald, T. N. Barry, and N. C. Friggens. 2012. E-Cow: An animal model that predicts herbage intake, milk yield and live weight change in dairy cows grazing temperate pastures, with and without supplementary feeding. *Animal* 6 (6): 980-993. http://dx.doi.org/10.1017/s1751731111002370.

Beniston, M., D. B. Stephenson, O. B. Christensen, C. A. Ferro, C. Frei, S. Goyette, K. Halsnaes, et al. 2007. Future extreme events in European climate: an exploration of regional climate model projections. *Climatic Change* 81 (1): 71-95.

Bouman, B., A. Schapendonk, W. Stol, and D. Van Kraalingen. 1996. Description of the growth model LINGRA as implemented in CGMS. Quantitative Approaches in Systems Analysis No. 7.

Brereton, A. J., S. A. Danielov, and D. Scott. 1996. *Agrometeorology of grass and grasslands for middle latitudes*. Agrometeorology of grass and grasslands for middle latitudes.

Carrere, P., F. Louault, and J. Soussana. 1997. Tissue turnover within grass-clover mixed swards grazed by sheep. Methodology for calculating growth, senescence and intake fluxes. *Journal of Applied Ecology*: 333-348.

Chilibroste, P., S. Tamminga, and H. Boer. 1997. Effects of length of grazing session, rumen fill and starvation time before grazing on dry-matter intake, ingestive behaviour and dry-matter rumen pool sizes of grazing lactating dairy cows. *Grass and Forage Science* 52 (3): 249-257. http://dx.doi.org/10.1111/j.1365-2494.1997.tb02355.x.

Cornell University. 2015. *Competency Area 2: Soil hydrology AEM* 2010 [cited 05-03-2015 2015]. Available from http://nrcca.cals.cornell.edu/soil/CA2/CA0212.1-3.php.

Dalley, D. E., J. R. Roche, C. Grainger, and P. J. Moate. 1999. Dry matter intake, nutrient selection and milk production of dairy cows grazing rainfed perennial pastures at different herbage allowances in spring. *Australian Journal of Experimental Agriculture* 39 (8): 923-931.

Delagarde, R., P. Faverdin, C. Baratte, and J. Peyraud. 2011. GrazeIn: a model of herbage intake and milk production for grazing dairy cows. 2. Prediction of intake under rotational and continuously stocked grazing management. *Grass and Forage Science* 66 (1): 45-60.

Dennis, P., M. R. Young, C. L. Howard, and I. J. Gordon. 1997. The response of epigeal beetles to varied grazing regimes on upland Nardus Stricta grasslands. *Journal of Applied Ecology* 34: 433-443.

Faverdin, P., C. Baratte, R. Delagarde, and J. L. Peyraud. 2011. GrazeIn: A model of herbage intake and milk production for grazing dairy cows. 1. Prediction of intake capacity, voluntary intake and milk production during lactation. *Grass and Forage Science* 66 (1): 29-44. http://dx.doi.org/10.1111/j.1365-2494.2010.00776.x.

Fulkerson, W. J., and D. J. Donaghy. 2001. Plant-soluble carbohydrate reserves and senescence - key criteria for developing an effective grazing management system for ryegrass-based pastures: a review. *Australian Journal of Experimental Agriculture* 41 (2): 261-275. http://dx.doi.org/http://dx.doi.org/10.1071/EA00062.

Gibb, M. J., C. A. Huckle, R. Nuthall, and A. J. Rook. 1997. Effect of sward surface height on intake and grazing behaviour by lactating Holstein Friesian cows. *Grass and Forage Science* 52 (3): 309-321. http://dx.doi.org/10.1111/j.1365-2494.1997.tb02361.x.

Hodgson, H. J. 1993. Sward studies: objectives and priorities. In *Sward Measurement Handbook*, edited by A. Davies, R.D. Baker, S.A. Grant and A.S. Laidlaw. Reading: Britisch Grassland Society.

Hodgson, J. 1981. Variations in the surface characteristics of the sward and the short-term rate of herbage intake by calves and lambs. *Grass and forage science* 36 (1): 49-57.

Holmes, C. W. 1974. "The Massey grass meter." In *Dairy Farming Annual*. Palmerston North, New Zealand: Massey University.

———. 1980. *Grass, its production and utilization*: Blackwell Scientific Publications.

Hurtado-Uria, C., D. Hennessy, L. Shalloo, D. O'Connor, and L. Delaby. 2013. Relationships between meteorological data and grass growth over time in the south of Ireland. *Irish Geography*.

Johnson, I., and J. Thornley. 1983. Vegetative crop growth model incorporating leaf area expansion and senescence, and applied to grass. In *Plant, Cell & Environment*.

Johnson, I. R., and A. J. Parsons. 1985. Use of a model to analyse the effects of continuous grazing managements on seasonal patterns of grass production. *Grass and Forage Science* 40 (4): 449-458. http://dx.doi.org/10.1111/j.1365-2494.1985.tb01776.x.

Jouven, M., P. Carrère, and R. Baumont. 2006. Model predicting dynamics of biomass, structure and digestibility of herbage in managed permanent pastures. 1. Model description. *Grass and Forage Science* 61 (2): 112-124.

Kolver, E., and L. Muller. 1998. Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. *Journal of dairy science* 81 (5): 1403-1411.

Koninklijk Nederlands Meteorologisch Instituut. 2015. *Weer* 2015 [cited 27-02-2015 2015]. Available from http://www.knmi.nl/waarschuwingen_en_verwachtingen/.

Lantinga, E. A. 1985. Productivity of grassland under continuous and rotational grazing.

Maxwell, T., A. Sibbald, A. Dalziel, R. Agnew, and D. Elston. 1994. The implications of controlling grazed sward height for the operation and productivity of upland sheep systems in the UK. 1. Effects of two annual stocking rates in combination with two sward height profiles. *Grass and Forage Science* 49 (1): 73-88.

Mayne, C., D. McGilloway, A. Cushnahan, A. Laidlaw, and D. Kilpatrick. 1997. The effect of sward height and bulk density on herbage intake and grazing behaviour of dairy cows. Paper read at Proceedings XVIII International Grassland Congress, Canada, June 1997.

Mayne, C., A. Rook, J. Peyraud, J. Cone, K. Martinsson, A. Gonzalez, A. Lúscher, et al. 2004. Improving the sustainability of milk production systems in Europe through increasing reliance on grazed pasture. Paper read at Land use systems in grassland dominated regions. Proceedings of the 20th General Meeting of the European Grassland Federation, Luzern, Switzerland, 21-24 June 2004.

Meehl, G. A., F. Zwiers, J. Evans, T. Knutson, L. Mearns, and P. Whetton. 2000. Trends in extreme weather and climate events: Issues related to modeling extremes in projections of future climate change*. *Bulletin of the American Meteorological Society* 81 (3): 427-436.

Meteovista. 2015. *Weather forecast for Wageningen* 2015 [cited 27-02-2015 2015]. Available from http://www.meteovista.co.uk/.

Metson, A., and W. Saunders. 1978. Seasonal variations in chemical composition of pasture: I. Calcium, magnesium, potassium, sodium, and phosphorus. *New Zealand journal of agricultural research* 21 (2): 341-353.

Milsom, T. P., S. D. Langton, W. K. Parkin, S. Peel, J. D. Bishop, J. D. Hard, and N. P. Moore. 2000. Habitat models of bird specie's distribution: an aid to the management of coastal grazing marshes. *Journal of Applied Ecology* 37: 706-727.

O'Donovan, M., J. Connolly, P. Dillon, M. Rath, and G. Stakelum. 2002. Visual assessment of herbage mass. *Irish journal of agricultural and food research*: 201-211.

O'mara, F. 2013. Monitoring grass from space. *TEAGASC Research*. (accessed

Remmelink, G., van Middelkoop, J., Ouweltjes, W., Wemmehove, H. . 2014. Handboek Melkveehouderij 2014. *Handboek Melkveehouderij* Handboek 29.

Schapendonk, A. H. C. M., W. Stol, D. W. G. Van Kraalingen, and B. A. M. Bouman. 1998. LINGRA, a sink/source model to simulate grassland productivity in Europe. *European Journal of Agronomy* 9 (2-3): 87-100.

Schils, R. L. M., M. H. A. De Haan, J. G. A. Hemmer, A. Van Den Pol-van Dasselaar, J. A. De Boer, A. G. Evers, G. Holshof, J. C. Van Middelkoop, and R. L. G. Zom. 2007. DairyWise, a wholes-farm dairy model. *Journal of Dairy Science* 90 (11): 5334-5346. http://dx.doi.org/10.3168/jds.2006-842.

Spitters, C. J. T., and A. H. C. M. Schapendonk. 1990. Evaluation of breeding strategies for drought tolerance in potato by means of crop growth simulation. *Plant and Soil* 123 (2): 193-203. http://dx.doi.org/10.1007/bf00011268.

Stewart, K. E. J., N. A. D. Bourn, and J. A. Thomas. 2001. An evaluation of three quick methods commonly used to assess sward height in ecology. *Journal of Applied Ecology* 38 (5): 1148-1154. http://dx.doi.org/10.1046/j.1365-2664.2001.00658.x.

Stichting Weidegang. 2012. Dynamisch weiden: welk systeem past?

Stobbs, T. 1970. Automatic measurement of grazing time by dairy cows on tropical grass and legume pastures. *Tropical Grasslands* 4 (3): 237-244.

Taweel, H. Z., B. M. Tas, H. J. Smit, A. Elgersma, J. Dijkstra, and S. Tamminga. 2005. Effects of feeding perennial ryegrass with an elevated concentration of water-soluble carbohydrates on intake, rumen function and performance of dairy cows. *Animal Feed Science and Technology* 121 (3–4): 243-256. http://dx.doi.org/http://dx.doi.org/10.1016/j.anifeedsci.2005.02.024.

Trlica, M. J. 2013. Grass Growth and Response to Grazing. In *Natural Resources Series*. Colorado.

Van den Pol-van Dasselaar, A., A. de Vliegher, D. Hennessy, J. Peyraud, and J. Pinxterhuis. 2011. Research methodology of grazing. In *Science*, edited by Communication Services. Lelystad.

van den Pol-van Dasselaar, A., J. Nolles, A. Philipsen, and M. Stienezen. 2014. Dynamics of dry matter intake in livestock production systems in the Netherlands. *The Future of European Grasslands*: 573.

van Dooren, H. J. C., Spörndly, E., Wiktorsson, H. 2002. Automatic milking and grazing. *Applied grazing strategies*.

Wright, I., and T. Whyte. 1989. Effects of sward surface height on the performance of continuously stocked spring-calving beef cows and their calves. *Grass and Forage Science* 44 (3): 259-266.

Zom, R. L. G., and G. Holshof. 2011. "Graze vision: a versatile grazing decision support model." In *Grassland Science in Europe, Volume 16*, 226-228. Irdning: Agricultural Research and Education Center (AREC) Raumberg-Gumpenstein.