# Cut and carry: Investigating the effects of increasing the proportion of grass in the diets of high yielding dairy cows

Research Programme: Increasing the value of fresh grass in the diet of the high yielding dairy cows

**Report prepared for DairyCo**

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## 1.1 Farmer recommendations

- When permanently-housed, high-yielding dairy cows were fed 25% or 50% of their diet as freshly cut grass, cows consumed more feed and produced an average of 5 kg per day less milk than those fed 100% TMR, but feed production costs were considerably lower. There were no consistent differences in milk quality or cow liveweights between the 25% grass-fed, 50% grass-fed and 100% TMR-fed groups. Grass-fed cows spent less time ruminating than 100% TMR-fed cows and this, coupled with higher intakes of lower quality feed, is likely to have caused reduced milk yields.

- Short mixing times (two to three minutes) were used in order to maintain grass integrity so that the grass and TMR mixtures were well presented to the cows. Straw was included in TMR to absorb moisture and TMR nutritional composition was designed to maximise milk yields. There was some evidence of elevated feed temperatures in the grass-fed groups. Maximum feed temperatures coincided with days when wet grass was left standing for longer periods of time. However, there are insufficient data available to determine whether high feed temperatures influenced feed intake or milk yields.

- Cows fed 50% of their diet as grass delivered the highest economic surplus under certain economic conditions. In the case of this system; a milk price of 32ppl or lower at a grass production cost of £15 per tonne. If milk prices decline then cut and carry systems become more attractive because of low production costs. If grass production costs were lower than £11 per tonne then 50% grass-fed cows delivered the highest economic surplus, regardless of milk price.

- Cows which were fed 25% of their diet as grass had approximately the same milk yields as those fed 50% grass, but with higher production costs. Under all economic scenarios the 25% grass-fed group delivered the lowest economic surplus, because feed costs remained high but without the benefits of high milk yields. It may not be beneficial to introduce smaller quantities of grass as part of a cut and carry system.

- TMR-only feeding delivered a higher economic surplus than both grass-fed groups at a TMR cost of £74 per tonne or lower, regardless of milk price. However, many farmers will produce grass at a lower cost than £15 per tonne, as used in this analysis. TMR-only feeding is particularly beneficial if milk prices are high due to high milk yields.

- Whether cut and carry systems are economically viable for a given farm will depend on a comparison of the relative costs of grass and TMR production assuming a decline in milk yields. Other, less immediate, benefits may also be considered, such as reduced risk of variable feed costs caused by fluctuations in international markets and greater control over grassland management.

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## 1.2 Executive summary

Cut and carry farming is an approach to dairy farming in which grass is cut daily in the field and delivered to permanently housed cows. There are benefits in using cut and carry systems because grass is cheaper to produce than total mixed ration (TMR) and grass is not subject to fluctuations in the cost of production caused by international markets. Across Great Britain, there is soil, weather and expertise with the potential to deliver high grass yields. However, the conditions required for this system to be beneficial to a farm business are currently unclear. The aim of this study was to provide information which can assist with this decision making, by testing the effects of adding fresh grass to the diets of high yielding dairy cows and monitoring changes to milk productivity, milk quality and profitability. Three diets were provided to three groups of 16 cows for 16 weeks. These diets were TMR-only (100% TMR), 25% grass (75% TMR) and 50% grass (50% TMR), balanced by dry matter content. Grass was cut every morning, mixed with TMR and delivered to cows.

**Table S1.** Average milk yields per day (kg), protein (%), butterfat (%), freshweight (FW) intake per day (kg), dry matter (DM) intake per day (kg) and time spent ruminating (%) or not ruminating (%) over the 16 week study for each diet ± standard error (s.e). Absolute differences between diets (/) are also presented.

| | 100% TMR | | 25% Grass | | 50% Grass | | TMR | TMR | 25% |
|---|---|---|---|---|---|---|---|---|---|
| | mean | s.e | mean | s.e | mean | s.e | / 25% | / 50% | / 50% |
| Milk yields | 35.73 | 0.37 | 30.19 | 0.52 | 31.40 | 0.46 | 5.54 | 4.33 | -1.21 |
| Protein | 3.00 | 0.01 | 2.98 | 0.01 | 2.89 | 0.02 | 0.02 | 0.11 | 0.09 |
| Butterfat | 3.34 | 0.04 | 3.51 | 0.06 | 3.40 | 0.05 | -0.17 | -0.06 | 0.11 |
| FW intake | 53.99 | 0.39 | 72.13 | 0.77 | 88.60 | 1.38 | -18.14 | -34.61 | -16.47 |
| DM intake | 20.05 | 0.26 | 19.31 | 0.21 | 18.00 | 0.29 | 0.74 | 2.05 | 1.31 |
| Ruminating | 48.83 | 2.28 | 38.54 | 1.95 | 38.25 | 2.79 | 10.29 | 10.58 | 0.29 |
| Not rumin | 50.32 | 2.12 | 60.98 | 2.05 | 61.18 | 2.93 | -10.66 | -10.86 | -0.20 |

- Milk yields from grass-fed cows were lower than milk yields from TMR-fed cows, by an average of 4.3 – 5.5 kg per day.
- Average milk yields from 25% grass-fed cows and 50% grass-fed cows were approximately equal throughout the experiment.
- There were no consistent differences in milk quality or cow weights between the diets.
- Intakes of feed by freshweight were highest for 50% grass-fed cows, lower for 25% grass-fed cows and were lowest for TMR-fed cows.
- Intakes of feed by dry matter were lowest for 50% grass-fed cows, higher for 25% grass-fed cows and were highest for TMR-fed cows.
- Grass-fed cows spent less time ruminating than TMR-fed cows. This, coupled with higher intakes of lower nutritional quality feed, is likely to have reduced milk yields.
- 50% grass-fed cows can deliver a higher economic surplus than those only fed TMR, depending on the relative costs of grass and TMR production as well as the prevailing milk selling price.
- 25% grass-fed cows were the least profitable across all scenarios, due to high feed costs.

# 2. Introduction

Cut and carry systems, where grass is cut daily and fed to high yielding dairy cows, have been proposed as a way of increasing the value of forage in dairy systems. This is important because feed and forage costs remain the largest costs to dairy farmers within Great Britain (DairyCo, 2013). Feeding total mixed ration (TMR) is the preferred option on many dairy farms because it produces high milk yields; however, TMR is an expensive feed to produce. Added to this, recent concerns over fluctuations in the availability and price of soya and other purchased feeds has led to an increase in farmer awareness of the value of home-grown, high quality forage. Home-grown feeds are low-cost and not subject to the market volatility that is associated with some purchased feeds.

The majority of farms within Great Britain are located in areas with potential for high herbage production (Peyraud and Delaby, 2001). Utilising this potential and increasing the amount of grass fed to cows could reduce feed costs, reduce the influence of external markets and increase profitability. There is uncertainty associated with the implementation of cut and carry systems because it is unclear how much grass could be added to cow diets and to what extent any changes to diets may change milk yields and quality. This study aimed to reduce this uncertainty and assist with farmer decision making by experimentally changing the proportion of fresh grass included in the diet of high yielding dairy cows and measuring changes to milk yields, milk quality and profitability.

## 2.1. Objectives

This study aimed to:

- Quantify changes in total feed intake, milk yield, milk quality and profitability as a result of adding fresh grass to the diet of high yielding dairy cows.
- Determine the effects of manipulating the proportion of fresh grass added to the diet on total feed intake, milk yield, milk quality and profitability.
- Understand cow behavioural changes resulting from a change in diet which may contribute towards shifts in feed intake, milk yields or milk quality.

# 3. Materials and Methods

### 3.1. Diets

Cows were allocated to one of three diets as part of a 16-week experiment. Diets varied in the proportion of fresh grass to TMR, with the proportion of fresh grass added to feed (on a dry matter (DM) basis), every morning (for TMR composition see appendix 2). By balancing grass inputs on a DM basis, the proportion of fresh grass included in feed was increased without increasing the total amount of DM available to the cows. The three diets were:

- Control: Total Mixed Ration (TMR) based on grass silage, maize silage, straw and concentrates formulated to provide sufficient nutrients for high milk yields and 0% grass (TMR-fed group).
- Low proportion of fresh grass: ration included 75% TMR mixed with 25% fresh grass (25% grass-fed group).
- High proportion of fresh grass: ration included 50% TMR mixed with 50% fresh grass (50% grass-fed group).

The study commenced on 28th April 2014. In the two weeks prior this date, the proportion of grass included in the diet of the grass-fed groups was increased gradually up to the targets.

### 3.2. Balanced groups

Forty-eight recently calved, high yielding, Holstein-Friesian dairy cows were identified for participation in this study. To ensure that the three groups of cows were balanced at the start of the experiment, cows were grouped into triplets of the most similar individuals and then allocated to one of the three treatments at random. Selection of individuals for each treatment was based on recordings taken in the week prior to commencement of the study (calving date, milk yield, milk composition and live weight).

### 3.3. Housing

Cows were housed throughout the experiment. The three groups were physically separated by barriers so that each group was allocated to one of three areas within the same building. Each group had a separate feeding area, separate bed cubicles and continual access to water.

### 3.4. Grass harvesting

In order to provide sufficient grass for this experiment 4.6 hectares of Perennial Ryegrass (*Lolium perenne*) pasture was required (assuming daily feeding at 24 kg DM per cow and daily grass growth at 65 kg DM per hectare). A 6 hectare field was therefore allocated to this experiment, providing a 1.4 hectare buffer. Harvesting occurred on a daily basis. In order to encourage vegetative grass growth, and to achieve target yield of 2600 – 2800 kg DM per hectare, any remaining grass in the pasture and in the buffer area was harvested and reduced to an approximate residual of 1500 kg DM per hectare after 21 days. This is in line with a three week rotation.

Grass was harvested daily at approximately 6:30 am using a Haldrup harvester (Haldrup Ltd, Germany). Three samples of grass were taken for immediate DM analysis using a microwave oven, following the methodology of Narasimhalu *et al* (1982). The amount of grass included in the diet of both grass-fed groups was adjusted according to microwave measured DM content every morning.

Grass was mixed with TMR in a mixing wagon for approximately two to three minutes and delivered to each of the three groups of cows at approximately 7:30 am. Short mixing times were chosen to maintain grass integrity so that feeds were well presented to the cows.

### 3.5. Measurements taken

#### 3.5.1. Diet composition

Three samples of each of the three feeds and three samples of grass were taken daily. DM content of each of these samples was determined by drying three sub-samples in an oven at 90°C for 24 hours. Daily samples of the three feeds and grass samples were bulked together at the end of each week. These weekly samples underwent a full wet chemistry analysis (DM, crude protein, ash, NDF, AHEE, NCGD, sugars, starch, ME) and for grass (DM, crude protein, ash, MAD fibre, ME). Feed chemical composition forms part of a separate report.

### 3.5.2. Milk yields, cow weights and milk composition

All cows were milked three times daily at approximately 07:30, 15:30 and 19:00 and weighed. Milk yield were recorded at each milking with samples taken weekly for subsequent analysis of fat, protein, urea and lactose. Milk samples were analysed weekly using a Milkoscan minor spectrophotometer (Foss Ltd, Denmark) and calibrated by the methods of AOAC (2000).

### 3.5.3. Feed intake

The amount of feed left uneaten each morning was weighed. This allowed calculation of freshweight (FW) feed intake each day for each of the three groups and therefore calculation of an average FW intake per cow. Since feed DM content was also measured daily this allowed calculation of daily group DM intake and of an average DM intake per cow.

Individual feed intake was also measured using saturated hydrocarbons (n-alkanes) in weeks nine and thirteen, with one faecal sample taken per cow per day (Dove and Mayes, 2006). Individual feed intake data forms part of a separate report.

### 3.5.4. Feed temperatures

Feed temperatures were measured three times in succession each day at approximately 7:00 pm using a temperature probe.

### 3.5.5. Cow behaviour

Behaviour of the animals in all three groups was monitored on four days. Every fifteen minutes each cow's behaviour was recorded, between the morning feed at 7:30 and the evening feed at 19:00. This allowed calculation of the average proportion of the time that each group spent carrying out a specific behaviour. Classifications were feeding, lying, grooming, standing or drinking. For lying and standing it was also recorded whether the cow was ruminating or not.

### 3.5.6. Economic assessment

Economic assessment of the cost of each of the three diets was based on the FW of grass and of TMR that was consumed each day by the cows. The default scenario for the cost of TMR was £84.12 per tonne (Feedbyte, 2014) and £15 per tonne for the cost of grass (DairyCo, 2012). These are total costs, including costs of production, land rental and equipment depreciation. Since these prices vary considerably over time and between farms, a lower cost grass and a lower cost TMR scenario were also used to calculate feed costs, assuming a reduction of £2.50 per tonne. Income generated for each scenario was based on the measured milk yields for each of the groups across a range of milk prices.

## 4. Results

### 4.1. Feed composition

The average DM content of TMR throughout the study was high at 36.8%, the 25% grass-fed groups feed was lower at 26.9% and the 50% grass-fed groups feed was lowest at 20.7%. The DM content of the diets for both grass-fed groups increased over time, alongside increases in the DM content of grass (appendix 1, table 1). The DM content of the diet for the TMR-fed group did not increase over time and the variability in DM content (represented by the low standard error) of TMR was considerably lower than grass.

The microwave method was used to measure feed DM content each day. This provided a relatively robust measure of the DM content of grass when compared with the oven dried method, over-estimating DM content by an average of 12% (figure 1). The average grass contribution to total DM intake, as measured by the oven dried method, was 24.5% and 52.5% for the target 25% grass-fed group and the 50% grass-fed group, respectively.

### 4.2. Milk yields

Milk yields from both groups of grass-fed cows were lower than milk yields from TMR-fed cows, by an average of 4.3 kg per day for each cow in the 50% grass-fed group and an average of 5.5 kg per day for each cow in the 25% grass-fed group.

Milk yields were greatest from the TMR-fed group from week one of the experiment, when compared with the 25% grass-fed group, and from week two of the experiment, when compared with the 50% grass-fed group (table 2). The TMR-fed group then outperformed both grass-fed groups for the rest of the experiment.

There was a lower rate of decline in milk yields over time for the TMR-fed group. Average milk yields per cow in the TMR-fed group declined by 0.12 kg per day, compared with a decline of 0.16 kg per day for the two grass-fed groups. As a result, the differences in yields between the TMR-fed group and the two grass-fed groups increased over time.

Despite some small differences in yields in weeks five, six and seven; overall milk yields from the two grass-fed groups were not significantly different.

### 4.3. Milk composition

There were no differences in the protein, butterfat or lactose content of milk when comparing the TMR-fed, 25% grass-fed and 50% grass-fed groups, though protein and butterfat generally increased over time (tables 3 and 4). There were some significant weekly differences in milk urea content between groups, although they varied in both magnitude and direction (table 5).

### 4.4. Cow weights

There were no significant differences in cow weights between the three treatments. Overall, cow weights for all three groups averaged 638 kg.

### 4.5. Feed consumption

The 50% grass-fed group consumed more FW feed than the 25% grass-fed group, with the TMR group consuming the least (figure 2). Overall, FW intakes averaged 89 kg per day, 72 kg per day and 54 kg per day for the 50% grass-fed, 25% grass-fed and TMR-fed groups, respectively. DM intakes showed the opposite pattern with the TMR-fed group consuming the most DM. DM intakes averaged 18 kg per day, 19 kg per day and 20 kg per day for the 50% grass-fed, 25% grass-fed and TMR-fed groups, respectively.

In week one of the study FW intakes were at their maximum and FW intakes declined for all three groups over time. This decline was greatest for the 50% grass-fed group and least for the TMR-fed group. Freshweight intakes declined over the 16 week study by an average of 13 kg, 12 kg and 2 kg for the 50% grass-fed, 25% grass-fed and TMR-fed groups, respectively.

The TMR-fed group consumed more DM at the start of the experiment. In the first three weeks the average DM consumed per cow was 16.0 kg per day, 18.5 kg per day and 19.9 kg per day for the 50% grass-fed, 25% grass-fed and TMR-fed groups, respectively. During the experiment the grass-fed groups increased their DM intake alongside increases in grass DM content. By the end of the experiment, all three groups were consuming approximately equal DM. In the final three weeks, the average DM consumed per cow was 18.2 kg per day, 19.0 kg per day and 19.0 kg per day for the 50% grass-fed, 25% grass-fed and TMR-fed groups, respectively.

### 4.6. Feed temperatures

There was some evidence of elevated feed temperatures in both grass-fed groups with maximum temperatures of 42°C recorded in the 50% grass-fed group, 33 °C recorded in the 25% grass-fed group. 30°C was recorded in the TMR-fed group. These recordings coincided with warmer days where wet grass was left standing for longer periods of time. Average temperatures were only moderately higher for the grass-fed groups; averaging 24°C in the 50% grass-fed group, 23°C in the 25% grass-fed group and 22°C in the TMR-fed group (figure 3). There are insufficient data available to determine whether elevated feed temperatures resulted in a change in feed intake or milk yields.

### 4.7. Cow behaviour

Cows in the grass-fed groups spent less time ruminating than cows in the TMR-fed group. Cows in the 25% grass-fed group and 50% grass-fed group spent 39% and 38% of their time ruminating, respectively. However, cows in the TMR-fed group spent 49% of their time ruminating (figure 4). Values are based on monitoring between the morning and evening feeds and do not include night-time activity, between 7pm and 7am.

### 4.8. Economic assessment

The TMR-fed group delivered higher milk yields but at higher costs of production than the grass-fed groups. Under the default scenario, if the milk price was 32ppl or lower then the low cost 50% grass-fed strategy delivered the highest surplus (table 6). If the milk price was 33ppl or higher then the high yielding TMR-fed group delivered the highest surplus.

The lower cost grass scenario hypothetically reduced grass costs by £2.50 per tonne resulting in an increase in the milk price at which the 50% grass-fed scenario delivered the highest surplus, from 32ppl to 35ppl. The value of the surplus per cow also increased accordingly. Overall, if grass production costs were lower than £11 per tonne then the 50% grass-fed scenario delivered the highest surplus, regardless of milk price.

The low cost TMR scenario hypothetically reduced TMR costs by £2.50 per tonne. This reduced the milk price at which the 50% grass-fed scenario delivered the highest surplus, from 32 ppl to 30ppl. If TMR production costs were reduced to £74 per tonne then the TMR-fed strategy delivered the highest surplus regardless of milk price. However, many farmers will produce grass at a lower cost than £15 per tonne, as used in this analysis.

Under all scenarios and milk prices the 25% grass-fed group produced the lowest surplus. This group did not maintain the benefits of high milk yields but retained high feed costs. Whether cut and carry systems are economically viable for a given farm will depend on a comparison of the relative costs of production for grass and TMR, assuming a decline in milk yields.

## 5. Conclusions

Adding fresh grass to a diet of TMR as part of a cut and carry feeding system was demonstrated to reduce milk yields without affecting milk quality but at a lower cost of production. Lower milk yields from grass-fed cows are likely to be the result of greater feeding effort, where cows consume a greater volume of lower quality feed, combined with a reduction in the time spent ruminating. This study demonstrates that cut and carry systems can be more profitable than TMR-only feeding systems, but only under certain economic conditions. Whether is it preferable for a particular farm to adopt a cut and carry system will depend on a comparison of relative costs of production for both TMR and grass alongside a potential reduction in milk yields. This study indicates that introducing small amounts of grass into feeds may not be cost effective, since feeds remain expensive to produce and lacks the benefits of high milk yields. Economic assessments at the farm level are needed to quantify the likely costs and benefits of introducing a cut and carry system, against a backdrop of variable milk prices and other less immediate financial benefits such as reduced risk from economically volatile purchased feeds.

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# 7. Appendix 1

**Table 1.** Average dry matter content (%) of the three feeds for each treatment group (TMR, 25% grass and 50% grass) and of grass ± standard error (s.e).

| Week | 100% TMR | | 25% Grass | | 50% Grass | | Grass | |
|---|---|---|---|---|---|---|---|---|
| | mean | s.e | mean | s.e | Mean | s.e | mean | s.e |
| 1 | 34.09 | 0.51 | 23.44 | 0.47 | 17.38 | 0.77 | 12.54 | 0.46 |
| 2 | 36.19 | 1.16 | 23.82 | 0.67 | 16.95 | 0.74 | 12.03 | 0.58 |
| 3 | 35.05 | 0.30 | 23.67 | 0.49 | 18.22 | 1.77 | 12.68 | 0.54 |
| 4 | 36.93 | 0.71 | 26.17 | 0.62 | 21.82 | 2.40 | 14.09 | 0.63 |
| 5 | 38.03 | 1.78 | 26.00 | 0.52 | 19.73 | 0.54 | 13.88 | 0.62 |
| 6 | 38.14 | 1.03 | 27.16 | 0.81 | 19.15 | 0.47 | 13.66 | 0.53 |
| 7 | 37.66 | 0.93 | 27.40 | 1.70 | 17.58 | 0.65 | 12.19 | 0.32 |
| 8 | 37.38 | 0.72 | 26.60 | 0.73 | 18.64 | 0.91 | 13.92 | 0.93 |
| 9 | 38.36 | 0.81 | 29.97 | 0.91 | 20.95 | 0.94 | 16.65 | 0.64 |
| 10 | 37.10 | 0.69 | 30.95 | 1.93 | 28.58 | 2.64 | 18.06 | 1.20 |
| 11 | 35.81 | 0.66 | 29.02 | 0.98 | 23.74 | 1.36 | 15.70 | 1.41 |
| 12 | 36.88 | 0.48 | 25.41 | 0.53 | 19.58 | 0.54 | 12.50 | 0.40 |
| 13 | 39.03 | 0.48 | 26.30 | 1.53 | 22.44 | 0.57 | 18.14 | 0.54 |
| 14 | 36.48 | 1.37 | 28.28 | 0.46 | 22.06 | 0.55 | 15.72 | 0.41 |
| 15 | 36.87 | 2.28 | 29.34 | 1.95 | 22.19 | 0.72 | 16.91 | 0.94 |
| 16 | 32.62 | 0.71 | 26.81 | 1.01 | 21.89 | 1.86 | 14.94 | 0.89 |

**Figure 1.** Relationship between oven measured dry matter content and microwave measured dry matter content (Oven measured = 0.88 x Microwave measured, $P < 0.05$).

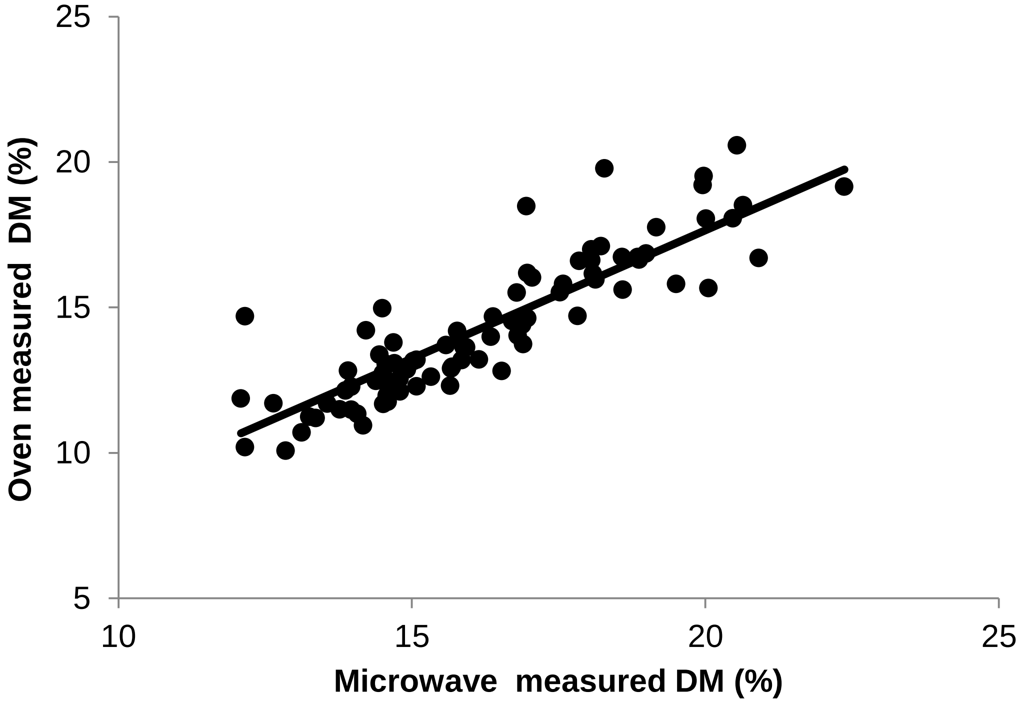

**Table 2.** Average milk yields (kg $d^{-1}$) for each treatment group ± standard error (s.e). Differences between groups (/) are also presented. Superscript letters denote significantly different treatment effects (P < 0.05).

| Week | 100% TMR | | 25% Grass | | 50% Grass | | TMR / 25% | TMR / 50% | 25% / 50% |
|---|---|---|---|---|---|---|---|---|---|
| | mean | s.e | mean | s.e | mean | s.e | | | |
| 1 | $39.61^{a}$ | 0.81 | $37.34^{b}$ | 0.38 | $38.12^{ab}$ | 0.56 | 2.28 | 1.49 | -0.79 |
| 2 | $40.49^{a}$ | 0.50 | $35.74^{b}$ | 0.49 | $36.35^{b}$ | 0.29 | 4.75 | 4.14 | -0.61 |
| 3 | $39.52^{a}$ | 0.40 | $34.72^{b}$ | 0.20 | $34.32^{b}$ | 0.30 | 4.80 | 5.21 | 0.40 |
| 4 | $38.99^{a}$ | 0.23 | $34.26^{b}$ | 0.39 | $33.18^{b}$ | 0.38 | 4.73 | 5.81 | 1.08 |
| 5 | $38.33^{a}$ | 0.38 | $33.52^{b}$ | 0.20 | $35.20^{c}$ | 0.25 | 4.81 | 3.13 | -1.68 |
| 6 | $37.47^{a}$ | 0.36 | $33.84^{b}$ | 0.41 | $35.59^{c}$ | 0.31 | 3.63 | 1.87 | -1.76 |
| 7 | $36.84^{a}$ | 0.20 | $33.83^{b}$ | 0.35 | $35.18^{c}$ | 0.34 | 3.02 | 1.67 | -1.35 |
| 8 | $37.04^{a}$ | 0.29 | $31.14^{b}$ | 0.39 | $32.58^{b}$ | 0.51 | 5.90 | 4.47 | -1.44 |
| 9 | $35.96^{a}$ | 0.33 | $29.05^{b}$ | 1.20 | $31.70^{b}$ | 0.44 | 6.91 | 4.26 | -2.65 |
| 10 | $36.31^{a}$ | 0.31 | $30.41^{b}$ | 1.44 | $31.90^{b}$ | 0.91 | 5.90 | 4.42 | -1.49 |
| 11 | $34.62^{a}$ | 0.38 | $28.29^{b}$ | 1.82 | $29.51^{b}$ | 0.82 | 6.33 | 5.11 | -1.22 |
| 12 | $34.25^{a}$ | 0.32 | $26.07^{b}$ | 1.26 | $28.97^{b}$ | 0.83 | 8.18 | 5.28 | -2.89 |
| 13 | $31.66^{a}$ | 1.39 | $21.48^{b}$ | 1.14 | $23.86^{b}$ | 1.18 | 10.18 | 7.79 | -2.38 |
| 14 | $30.55^{a}$ | 0.45 | $22.77^{b}$ | 1.05 | $24.28^{b}$ | 0.89 | 7.79 | 6.27 | -1.51 |
| 15 | $28.84^{a}$ | 0.91 | $25.04^{a}$ | 1.45 | $25.20^{a}$ | 1.31 | 3.81 | 3.64 | -0.17 |
| 16 | $27.85^{a}$ | 0.40 | $22.09^{b}$ | 0.96 | $23.54^{b}$ | 0.06 | 5.76 | 4.31 | -1.45 |

**Table 3.** Average milk protein content (%) for each treatment group ± standard error (s.e). Differences between groups (/) are also presented. Superscript letters denote significantly different treatment effects (P < 0.05).

| Week | 100% TMR | | 25% Grass | | 50% Grass | | TMR / 25% | TMR / 50% | 25% / 50% |
|---|---|---|---|---|---|---|---|---|---|
| | mean | s.e | mean | s.e | mean | s.e | | | |
| 1 | $2.88^{a}$ | 0.04 | $2.84^{a}$ | 0.07 | $2.78^{a}$ | 0.04 | 0.04 | 0.11 | 0.06 |
| 2 | $2.91^{a}$ | 0.04 | $2.85^{a}$ | 0.08 | $2.79^{a}$ | 0.04 | 0.06 | 0.12 | 0.06 |
| 3 | $2.89^{a}$ | 0.05 | $2.89^{a}$ | 0.08 | $2.73^{a}$ | 0.05 | 0.00 | 0.16 | 0.16 |
| 4 | $2.90^{a}$ | 0.05 | $2.91^{a}$ | 0.08 | $2.80^{a}$ | 0.07 | -0.01 | 0.10 | 0.11 |
| 5 | $2.93^{a}$ | 0.06 | $3.01^{a}$ | 0.08 | $2.95^{a}$ | 0.06 | -0.08 | -0.02 | 0.06 |
| 6 | $2.90^{a}$ | 0.05 | $2.95^{a}$ | 0.08 | $2.93^{a}$ | 0.08 | -0.05 | -0.04 | 0.01 |
| 7 | $2.98^{a}$ | 0.05 | $2.97^{a}$ | 0.08 | $2.96^{a}$ | 0.07 | 0.02 | 0.03 | 0.01 |
| 8 | $2.99^{a}$ | 0.04 | $2.92^{a}$ | 0.08 | $2.81^{a}$ | 0.04 | 0.06 | 0.17 | 0.11 |
| 9 | $3.00^{a}$ | 0.05 | $3.03^{a}$ | 0.08 | $2.92^{a}$ | 0.05 | -0.03 | 0.08 | 0.11 |
| 10 | $3.03^{a}$ | 0.06 | $3.02^{a}$ | 0.09 | $2.93^{a}$ | 0.06 | 0.01 | 0.10 | 0.09 |
| 11 | $3.13^{a}$ | 0.08 | $3.06^{a}$ | 0.08 | $2.94^{a}$ | 0.06 | 0.07 | 0.18 | 0.12 |
| 12 | $3.10^{a}$ | 0.06 | $3.02^{a}$ | 0.08 | $2.97^{a}$ | 0.06 | 0.08 | 0.13 | 0.05 |
| 13 | $3.04^{a}$ | 0.06 | $2.88^{a}$ | 0.09 | $2.80^{a}$ | 0.05 | 0.15 | 0.24 | 0.09 |
| 14 | $3.10^{a}$ | 0.06 | $3.00^{a}$ | 0.10 | $2.95^{a}$ | 0.06 | 0.10 | 0.15 | 0.05 |
| 15 | $3.18^{a}$ | 0.08 | $3.10^{a}$ | 0.08 | $3.00^{a}$ | 0.07 | 0.08 | 0.18 | 0.10 |
| 16 | $3.16^{a}$ | 0.06 | $3.23^{a}$ | 0.17 | $3.04^{a}$ | 0.07 | -0.06 | 0.12 | 0.18 |

**Table 4.** Average milk butterfat content (%) for each treatment group ± standard error (s.e). Differences between groups (/) are also presented. Superscript letters denote significantly different treatment effects (P < 0.05).

| Week | 100% TMR | | 25% Grass | | 50% Grass | | TMR | TMR | 25% |
|---|---|---|---|---|---|---|---|---|---|
| | mean | s.e | mean | s.e | mean | s.e | / 25% | / 50% | / 50% |
| 1 | 3.06$^{a}$ | 0.14 | 3.26$^{a}$ | 0.21 | 3.22$^{a}$ | 0.15 | -0.21 | -0.17 | 0.04 |
| 2 | 3.24$^{a}$ | 0.12 | 3.38$^{a}$ | 0.22 | 3.46$^{a}$ | 0.18 | -0.14 | -0.22 | -0.08 |
| 3 | 3.20$^{a}$ | 0.17 | 3.18$^{a}$ | 0.15 | 3.35$^{a}$ | 0.16 | 0.03 | -0.15 | -0.18 |
| 4 | 2.89$^{a}$ | 0.13 | 2.94$^{a}$ | 0.20 | 3.18$^{a}$ | 0.20 | -0.05 | -0.29 | -0.24 |
| 5 | 3.22$^{a}$ | 0.20 | 3.49$^{a}$ | 0.35 | 3.63$^{a}$ | 0.30 | -0.27 | -0.41 | -0.14 |
| 6 | 3.08$^{a}$ | 0.19 | 3.37$^{a}$ | 0.18 | 3.26$^{a}$ | 0.24 | -0.29 | -0.18 | 0.11 |
| 7 | 3.35$^{a}$ | 0.19 | 3.39$^{a}$ | 0.23 | 3.62$^{a}$ | 0.10 | -0.04 | -0.27 | -0.23 |
| 8 | 3.38$^{a}$ | 0.16 | 3.52$^{a}$ | 0.34 | 3.14$^{a}$ | 0.22 | -0.14 | 0.24 | 0.38 |
| 9 | 3.38$^{a}$ | 0.18 | 3.62$^{a}$ | 0.15 | 3.67$^{a}$ | 0.14 | -0.24 | -0.29 | -0.05 |
| 10 | 3.56$^{a}$ | 0.16 | 3.65$^{a}$ | 0.21 | 3.79$^{a}$ | 0.24 | -0.09 | -0.23 | -0.13 |
| 11 | 3.45$^{a}$ | 0.15 | 3.44$^{a}$ | 0.20 | 3.13$^{a}$ | 0.25 | 0.01 | 0.32 | 0.31 |
| 12 | 3.49$^{a}$ | 0.17 | 3.77$^{a}$ | 0.21 | 3.74$^{a}$ | 0.15 | -0.28 | -0.26 | 0.03 |
| 13 | 3.86$^{a}$ | 0.21 | 3.47$^{a}$ | 0.23 | 3.10$^{a}$ | 0.24 | 0.39 | 0.76 | 0.37 |
| 14 | 3.40$^{a}$ | 0.22 | 4.10$^{a}$ | 0.41 | 3.72$^{a}$ | 0.16 | -0.71 | -0.32 | 0.38 |
| 15 | 4.06$^{a}$ | 0.19 | 3.70$^{a}$ | 0.22 | 3.88$^{a}$ | 0.26 | 0.35 | 0.17 | -0.18 |
| 16 | 3.91$^{a}$ | 0.25 | 4.32$^{a}$ | 0.37 | 3.68$^{a}$ | 0.21 | -0.41 | 0.23 | 0.65 |

**Table 5.** Average milk urea content (%) for each treatment group ± standard error (s.e). Differences between groups (/) are also presented. Superscript letters denote significantly different treatment effects (P < 0.05).

| Week | 100% TMR | | 25% Grass | | 50% Grass | | TMR | TMR | 25% |
|---|---|---|---|---|---|---|---|---|---|
| | mean | s.e | mean | s.e | mean | s.e | / 25% | / 50% | / 50% |
| 1 | 0.025$^{a}$ | 0.001 | 0.026$^{ab}$ | 0.001 | 0.030$^{b}$ | 0.001 | -0.001 | -0.005 | -0.004 |
| 2 | 0.028$^{a}$ | 0.002 | 0.026$^{a}$ | 0.001 | 0.028$^{a}$ | 0.001 | 0.001 | 0.000 | -0.002 |
| 3 | 0.022$^{a}$ | 0.001 | 0.022$^{a}$ | 0.001 | 0.025$^{a}$ | 0.001 | 0.000 | -0.003 | -0.003 |
| 4 | 0.023$^{a}$ | 0.001 | 0.020$^{a}$ | 0.001 | 0.020$^{a}$ | 0.001 | 0.003 | 0.003 | 0.000 |
| 5 | 0.027$^{a}$ | 0.001 | 0.025$^{b}$ | 0.001 | 0.030$^{a}$ | 0.001 | 0.003 | -0.003 | -0.006 |
| 6 | 0.026$^{a}$ | 0.001 | 0.020$^{b}$ | 0.001 | 0.022$^{ab}$ | 0.001 | 0.006 | 0.004 | -0.002 |
| 7 | 0.023$^{a}$ | 0.001 | 0.023$^{a}$ | 0.001 | 0.029$^{b}$ | 0.002 | 0.000 | -0.006 | -0.006 |
| 8 | 0.034$^{a}$ | 0.002 | 0.033$^{b}$ | 0.001 | 0.039$^{a}$ | 0.002 | 0.001 | -0.005 | -0.006 |
| 9 | 0.027$^{a}$ | 0.001 | 0.022$^{b}$ | 0.001 | 0.024$^{ab}$ | 0.001 | 0.006 | 0.003 | -0.002 |
| 10 | 0.026$^{a}$ | 0.001 | 0.024$^{a}$ | 0.001 | 0.026$^{a}$ | 0.001 | 0.001 | -0.001 | -0.002 |
| 11 | 0.024$^{a}$ | 0.001 | 0.024$^{a}$ | 0.001 | 0.019$^{b}$ | 0.001 | 0.000 | 0.005 | 0.005 |
| 12 | 0.026$^{a}$ | 0.001 | 0.027$^{a}$ | 0.002 | 0.035$^{b}$ | 0.001 | -0.001 | -0.009 | -0.009 |
| 13 | 0.025$^{a}$ | 0.002 | 0.023$^{a}$ | 0.001 | 0.026$^{a}$ | 0.001 | 0.002 | -0.001 | -0.002 |
| 14 | 0.020$^{a}$ | 0.001 | 0.022$^{a}$ | 0.002 | 0.031$^{b}$ | 0.002 | -0.002 | -0.012 | -0.010 |
| 15 | 0.023$^{a}$ | 0.002 | 0.022$^{a}$ | 0.001 | 0.028$^{b}$ | 0.002 | 0.001 | -0.006 | -0.007 |
| 16 | 0.022$^{a}$ | 0.002 | 0.023$^{a}$ | 0.002 | 0.025$^{a}$ | 0.001 | -0.001 | -0.003 | -0.002 |

**Figure 2.** Freshweight (FW) consumed per cow over the experiment for the TMR group (blue, FW = -0.12 x day + 95.13, $P < 0.05$), 25% group (red, FW = -0.11 x day + 78.20, $P < 0.05$) and 50% group (green, y = -0.07 x day + 58.06, $P < 0.05$).

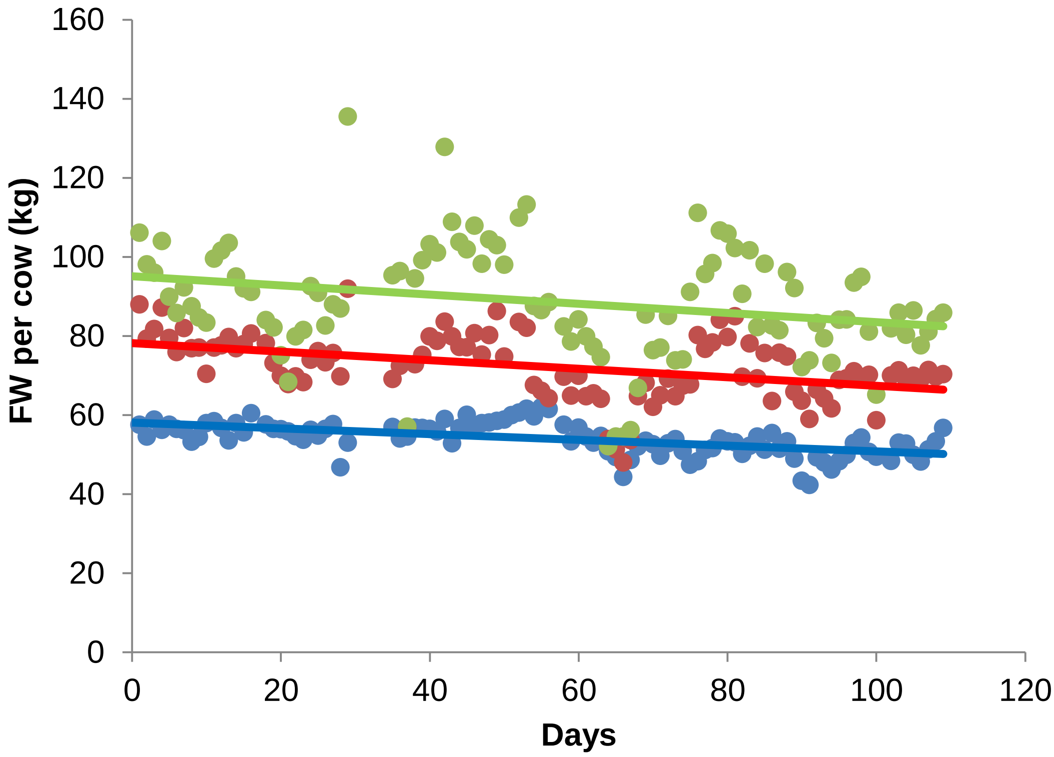


**Figure 3.** Feed temperatures over the experiment for the TMR group (blue), 25% group (red) and 50% group (green). Values are the means of three measurements.

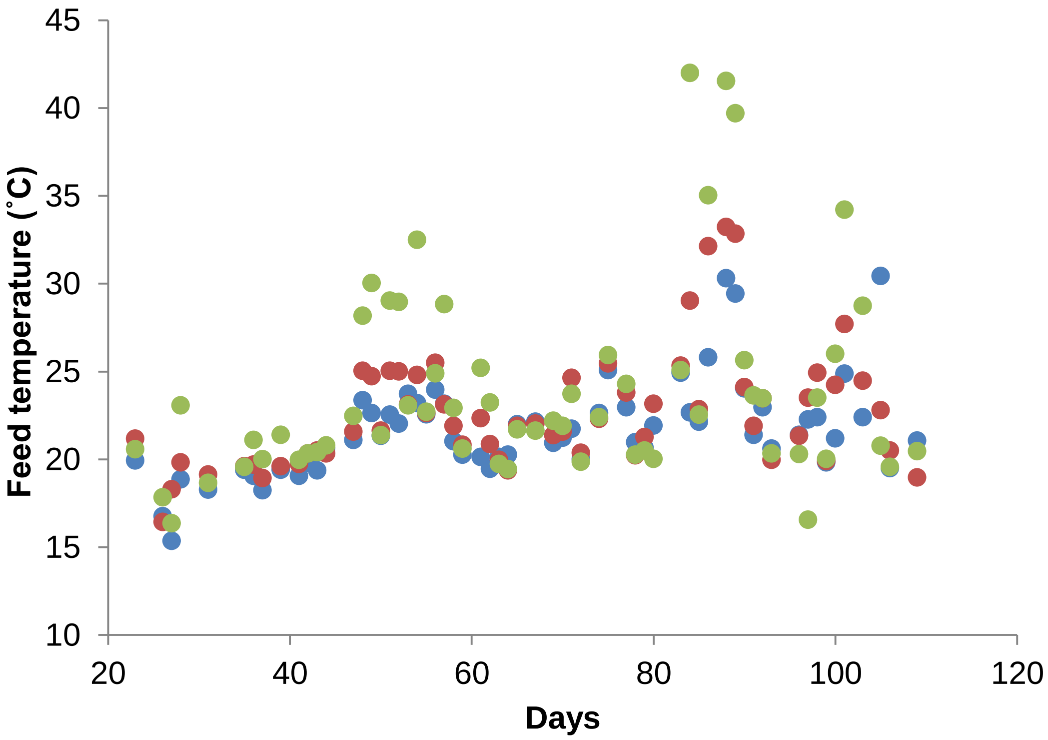

**Figure 4.** Boxplots of the average proportion of time spent a) ruminating and b) not ruminating. Letters denote significantly different treatment effects (P < 0.05).

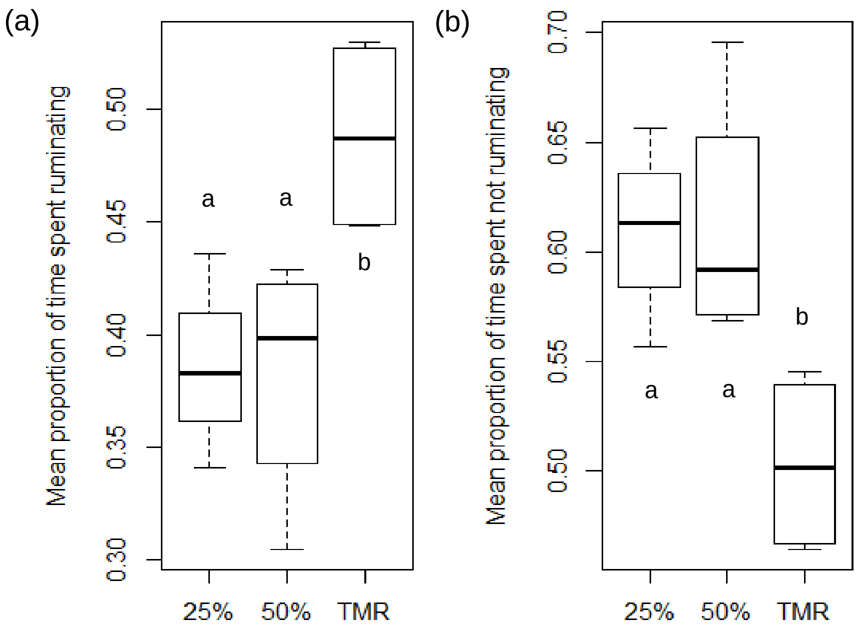


**Table 6.** Economic surplus (£) per cow after 16 weeks for a range of milk prices (ppl). Three scenarios for TMR and grass production costs are given. Bold denotes the largest surplus for a given scenario. Variables were TMR and grass costs of production and milk price.

| | Default assumptions | | | Lower cost grass | | | Lower cost TMR | | |
|---|---|---|---|---|---|---|---|---|---|
| TMR | 84.12 | 84.12 | 84.12 | 84.12 | 84.12 | 84.12 | 81.62 | 81.62 | 81.62 |
| Grass | 15.00 | 15.00 | 15.00 | 12.50 | 12.50 | 12.50 | 15.00 | 15.00 | 15.00 |
| Milk (p) | TMR | 25% | 50% | TMR | 25% | 50% | TMR | 25% | 50% |
| 25 | 409.94 | 344.15 | **440.99** | 409.94 | 352.20 | **456.50** | 423.42 | 354.12 | **447.63** |
| 26 | 444.48 | 373.27 | **471.29** | 444.48 | 381.33 | **486.80** | 457.96 | 383.24 | **477.93** |
| 27 | 479.02 | 402.39 | **501.59** | 479.02 | 410.45 | **517.10** | 492.50 | 412.36 | **508.22** |
| 28 | 513.56 | 431.51 | **531.88** | 513.56 | 439.57 | **547.39** | 527.05 | 441.49 | **538.52** |
| 29 | 548.11 | 460.64 | **562.18** | 548.11 | 468.69 | **577.69** | 561.59 | 470.61 | **568.82** |
| 30 | 582.65 | 489.76 | **592.48** | 582.65 | 497.82 | **607.99** | 596.13 | 499.73 | **599.11** |
| 31 | 617.19 | 518.88 | **622.77** | 617.19 | 526.94 | **638.28** | **630.68** | 528.85 | 629.41 |
| 32 | 651.74 | 548.00 | **653.07** | 651.74 | 556.06 | **668.58** | **665.22** | 557.98 | 659.71 |
| 33 | **686.28** | 577.13 | 683.37 | 686.28 | 585.18 | **698.88** | **768.85** | 645.34 | 750.60 |
| 34 | **720.82** | 606.25 | 713.66 | 720.82 | 614.31 | **729.17** | **734.30** | 616.22 | 720.30 |
| 35 | **755.36** | 635.37 | 743.96 | 755.36 | 643.43 | **759.47** | **768.85** | 645.34 | 750.60 |
| 36 | **789.91** | 664.49 | 774.25 | **789.91** | 672.55 | 789.77 | **803.39** | 674.47 | 780.89 |
| 37 | **824.45** | 693.62 | 804.55 | **824.45** | 701.67 | 820.06 | **837.93** | 703.59 | 811.19 |
| 38 | **858.99** | 722.74 | 834.85 | **858.99** | 730.80 | 850.36 | **872.48** | 732.71 | 841.49 |

# 8. Appendix 2

**Table 7.** Total mixed ration (TMR) composition showing average dry matter (DM) content of each component, target freshweight (FW per animal) and target dry matter (DM per animal).

| Component | DM<br>% | FW per animal<br>kg | DM per animal<br>kg |
|---|---|---|---|
| Concentrates | 85.00 | 8.50 | 7.22 |
| TMR minerals | 100.00 | 0.20 | 0.20 |
| Energiser | 100.00 | 0.20 | 0.20 |
| Megalac | 95.00 | 0.20 | 0.19 |
| Straw | 83.00 | 1.00 | 0.83 |
| Vitagold | 32.00 | 5.00 | 1.60 |
| Maize silage | 35.00 | 12.00 | 4.20 |
| Grass silage | 27.00 | 24.00 | 6.48 |

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