Analysis of Hydroponically Grown Fodder as Livestock Feed

Abstract: Nutritional analysis of hydroponically grown fodder in the UK and Ireland which demonstrates key benefits of feeding cattle and other ruminants green fodder compared to other fresh crops. Our research primarily focusses on the nutritional analysis of sprouted barley fodder in order to improve our understanding of the potential benefits and challenges of a hydroponic fodder system on a global and commercial scale.

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Introduction

Hydroponic systems are an alternative method to conventional agriculture, where nutrient-rich solutions are applied directly to a suspended root system. These systems are enclosed thus minimizing the need for water, large areas of agricultural land, and pesticides. Although this is a relatively new application, there have been many demonstrated nutritional benefits of feeding animals hydroponic feed instead of grain-based diets.

Recent studies have demonstrated several benefits of feeding hydroponic green fodder to ruminants (cattle, goats, and sheep) instead of conventional livestock feed such as alfalfa and hay. Benefits demonstrated include improvements to digestion, milk production, reproduction, and weight management (Agius, et al. 2019; Nonigopal, 2019; Harvey, 2016).

Hydroponic barley fodder is a young tender grass grown from a cereal grain. Barley fodder has a high nutritional value including high levels of crude protein, little dry matter, and beneficial minerals and enzymes. Specifically, barley fodder eliminates enzyme inhibitors which in turn helps absorption of the fodder and puts less stress on the animal's digestive system. (Kide, at al. 2015) Furthermore, barley fodder contains sucrose, fructose, fructans, glucose, lactose and maltose which allows the animal to produce energy more efficiently. Additionally, there are significantly higher levels of minerals and vitamins in sprouted barley compared to grain. (Harvey, 2016).

Unlike sprouted fodder, grains are high in phytates which inhibit mineral absorption and important enzymes such as trypsin, requiring that the pancreas work harder to digest grain. Additionally, grains are primarily composed of starch, which can lead to fermentation and D-lactic acid build up in the rumen. D-lactic acid can cause an acidic environment in the rumen and reduce the efficiency of the digestive process.

Green fodder also presents several advantages to the environment such as conserving water, reducing grow time, minimizing land use, and limiting pesticide use (Walls, 2014).

Given current human diets and consumption, we would need to utilise 98% of all available land, including deserts and ice-covered land to feed the world's population. According to Alexander et al., 2016, pasture for animal's accounts for 68% of all agricultural land with an additional 33% used for animal feed. There is simply not enough land to support our current needs and it will be vitally important to shift of agricultural practices to include innovative solutions (Barbosa, et al. 2015). Hydroponic systems could be the answer to preventing a food crisis. Estimates show that 50 sq. m hydroponic unit yields the same amount of fodder as 1 ha of land (Naik and Singh, 2013).

Analysis of hydroponic fodder and comparable samples

	Fresh Grass W/C 02.09.19	Hydroponic Barley Fodder	Alfalfa Hay
DM %[1]	12.9	13.7	89.9
ME MJ	11.3	12.6	8.47
CP %	25	16.43	18.6
NDF %	47	33	41.6
Oil %	5.5		3
Sugars %	5.7		4.5
UFL	0.95	1.09	0.68
RFC g/kg DM	122	252	73
Acid Load g/kg DM	32	49	24
Fibre Index g/kg DM	204	144	174
RUFAL g/kg DM	19	12.1	9.7
NFEPB g/kg DM	88	4	74
Yield ME Litres	7.02	9.55	1.57
Yield MP Litres	14.63	11.89	12.23
Excess MPN	573	115	283
NFEPB g/day	881	40	740
Estimated Milk Loss due to NFEPB litres/day	0.65	0	0.5

***Table 1 – nutritional analysis of common livestock feed sources vs hydroponic fodder**

Analysis Terminology:

Dry Matter (DM)	Dry matter refers to material remaining after water is removed, and the moisture content reflects the amount of water present in the feed ingredient. The nutrients in feeds, required by the animal for maintenance, growth, pregnancy, and lactation, are part of the DM portion of the feed.
Metabolisable Energy (ME)	Metabolisable energy—(ME) is the difference between the digestible energy and the loss of energy in the form of urine and methane gas released by rumen and hind–gut microbes. ME is approximately 81% of DE in ruminants, which means that approximately 19% of DE is lost as urine and methane energy. Measure in Megajoules (MJ).
Metabolisable Protein (MP)	Metabolisable Protein (MP): is a measure of total amino acids that are available for intestinal digestion to meet maintenance, growth, production and fetal growth. MP is evaluated by the sum of microbial crude protein (MCP) flowing from the rumen plus the digestible rumen undegraded protein (dRUP) from feed consumed.
Crude Protein (CP)	Crude Protein (CP): Crude protein measures the nitrogen content of a feedstuff, including both true protein and non-protein nitrogen. DIP also includes non-protein nitrogen found in feeds or ingredients. Undegradable Intake Protein (UIP): The rumen-undegradable portion of an animal's crude protein intake.
NDF (Neutral Detergent Fibre)	Neutral detergent fibre (NDF) is the most common measure of fibre used for animal feed analysis, but it does not represent a unique class of chemical compounds. NDF measures most of the structural components in plant cells (i.e. lignin, hemicellulose and cellulose), but not pectin. Further analysis can be done to the sample to determine individual components such as acid detergent fibre (ADF) analysis. The process of determining NDF content involves a neutral detergent that dissolves plant pectins, proteins, sugars and lipids. This leaves behind the fibrous parts such as cellulose, lignin and hemicellulose.
UFL (Unite Forragere Lait)	UFLs (Unite forragere lait) the energy in feed and forage are expressed in UFLs.
RFC (Refined Functional Carbohydrates)	Refined functional carbohydrates (RFC) help to provide a healthy foundation for animals by delivering valuable nutrition to increase growth and productivity. RFCs can help maintain overall animal health - directly and indirectly.
Acid Load	The dietary acid load is determined by the balance of acid-inducing materials that make up a diet. Acid load is most commonly elevated by poor quality forage.

RUFAL (Rumen Unsaturated Fatty Acid Load)	RUFAL stands for Rumen Unsaturated Fatty Acid Load and is a number meant to show the total unsaturated fatty acid level entering the rumen from all feeds consumed each day. It was designed to be a better indicator of fermentation disruption in the rumen than just relying on the percentage of fat added to the diet.
NFEPB (Nutriopt Fermentable Energy Protein Balance)	Nutriopt Fermentable Energy Protein Balance (NFEPB) is a useful tool to help manage the energy protein balance during grazing. The NFEPB figure is the difference between the available rumen-degradable protein and the rumen-degradable protein required for maximum microbial protein synthesis based on the available amount of fermentable carbohydrates. If the NFEPB figure is positive, the diet is high in protein, whilst if NFEPB is negative, the diet is high in fermentable carbohydrate. A perfectly balanced diet will have a NFEPB of 0g/day. The recommended NFEPB for a complete diet is between 0 and 200g/day, as higher figures will result in a significant waste of rumen fermentable protein.
Yield ME Litres	Milk yield able to be produced from metabolisable energy.
Yield MP Litres	Milk yield able to be produced from metabolisable protein.
Excess MPN	Metabolisable protein (MPE) is the protein most efficiently utilised by dairy cows. Proper diets deliver correct levels of metabolisable protein (MPE) and not to overload the diet with rumen degradable protein (MPN), which the cow cannot use. Moving away from basing rationing on crude protein takes the guesswork out of what cows really need. Basing rationing on crude protein levels is wasteful as well as being detrimental to cow health.

Glossary:

Yield	Crop yield is the output weight of the crop as a ratio to the input weight. E.g. 8:1 is 8kg of fodder output for each 1kg of grain in.
NFT (Nutrient Film Technique)	Nutrient film technique (NFT) is a hydroponic technique where in a very shallow stream/film of water containing dissolved nutrients required for crop growth is re-circulated past the bare roots of plants in a watertight gully/channel.
Nutrient	A water-soluble fertiliser to aid crop growth.
TMR (Total Mixed Ration)	A total mixed ration (TMR) is the entire diet that is fed to cattle. This is often a complex blend of forage, grains and concentrates.

Analysis of hydroponic fodder and comparable samples

The dry matter value (DM) of hydroponic fodder is similar to fresh grass. Unlike fodder or fresh grass, hay has higher dry matter due to the production process. Hay is often used as feed because it can be easily stored for long periods of time but consequently takes longer for the animal to digest and break down cellulose and lignin structures.

Fresh grass and hydroponic fodder should be used within 1 to 2 days of harvesting. This is not usually an issue with fodder, as it can be produced fresh each day. Fresh grass, however, can only be utilised for a limited period of growth through the year, depending on climate.

Metabolisable energy (ME) is higher in hydroponic fodder than either of the comparable samples. This is due to increased digestibility and whilst comparable to grass, is substantially higher than that of hay.

Typically, grazed grass is high in crude protein (CP), ranging from 15–25 %. However, in well managed pastures, particularly in the spring, a CP of 25 % and higher is becoming more common. This is supported by (GrassWatch, Trouw Nutrition, Ireland) which found 30% CP in grazed grass. Offering cows, a low CP concentrate when they are grazing often does not result in reducing the CP in the total ration to 16–18 %. For example, if cows that are eating 15kg (DM) of 25% CP grass receive 7kg of a 12% CP concentrate, the overall diet will have a CP over 20%.

Grass also contains more protein which is highly degradable in the rumen (typically 70–80 % of CP). Due to the high rate of protein breakdown in the rumen and limited available energy, microorganisms cannot efficiently capture nitrogen in the rumen to synthesize microbial proteins. This could result in the rumen not being utilised efficiently. As a result, many farmers turn to concentrates that are high in rumen fermentable carbohydrates to ensure that the rumen microbes can utilise as much of the protein as possible.

In contrast, analysis shows that CP is lower in fodder than in grass or hay and therefore may provide a more balanced diet and improve ruminant health. This is supported by the NDF value which shows that fibre content is substantially lower in fodder. This process could be modified to increase fibre content, but it would most likely require a longer growth cycle and supplemental photosynthesis. In a typical hydroponic system, the fodder is harvested within 6-8 days before photosynthesis is needed for development, drawing most of its energy requirements from the seed itself.

This energy value is expressed as a UFL, which is typically higher in fodder than in the other samples. In terms of value for money in livestock feed, the UFL gives a useful value in understanding energy content as it relates to cost.

Refined Functional Carbohydrates (RFC's) in fodder are usually 2 times higher than grass and three times higher than hay, respectively. This is an impressive metric in understanding the energy value that livestock can take from their feed source. As this energy is not being used for digestion, it can be utilised for overall well-being and productivity. By sprouting the seed in a hydroponic system, the fodder has a better RFC value than simply feeding the whole grain, placing less load on the rumen.

Acid load as an important consideration in the diet of livestock; no more so than in dairy cattle. Rumen acidosis is related to the amount of acid produced from fermented feed and the capacity of the feed to support salivary buffer production. Because hydroponic fodder can be grown and fed on a daily, fresh basis, the acid load is reduced, as opposed to fermented (grass silage/maize) diets. Large intakes of rapidly fermentable carbohydrates can lead to unbalanced Subacute Rumen Acidosis (SARA), which leads to an increase of organic acids in the rumen (Owens et al., 1998). The length of time per day when ruminal pH is below 5.6 (Keunen et al., 2002) or below 5.8 (Krause et al., 2002b; Krause and Combs, 2003) is a more important determinant of rumen acidosis than the mean daily ruminal pH (Rustomo et al. 2007).

RUFAL values can also be used as an indicator of acid load and ruminant health. These values are used more common in modern farming where a total mixed ration approach is utilised in order to optimise milk or beef production. A major part of any TMR is generally a fermented grass-based crop such as grass silage. Acid load and RUFAL values are harder to balance when using fermented crops, as opposed to fresh.

NFEPB values are also very useful when comparing multiple different samples. A baseline value of 0 is an optimal balance between protein and carbohydrates - at a rumen microbial level - and fodder is quite considerably closer to this baseline value than f grass or hay. This NFEPB value is considered one of the most useful metrics within the analysis as it provides a point of balance to measure the efficacy of each sample.

Summary

The notion of creating a balanced diet for livestock, to optimise production, provides the underpinnings of the entire global animal nutrition industry. Results in the table (*figure 1) highlight strengths and weaknesses across the sample range, where each could be included in a TMR to satisfy a particular requirement.

However, by considering the results as a whole, it is quite apparent that fodder is balanced across the range and therefore promotes ruminant health and laterally animal well-being that more intensive, concentrated or fermented forage-based diets cannot achieve. With this increase in animal health comes a range of secondary benefits including reduced methane production, reduced medicine use and reduced reliance on concentrate feeds.

Perceived Benefits of Fodder

Brunetti et al. 1999, was one of the first to demonstrate that hydroponic sprouting removes much of the grain starch that can lead to overly acidic conditions in the rumen. Brunetti also showed that sprouted barley has higher levels of a variety of vitamins, minerals and sugars, and that these are in highly digestible forms within the sprouted feed including 23 times more vitamin A than carrots, 22 times more vitamin B than lettuce and 14 times more vitamin C than citrus fruits.

Fresh sprouting barley fodder enables the digestive system to process food more efficiently than grain. Fodder eliminates phytates to improve mineral absorption and also eliminates enzyme inhibitors to improve the digestive process. It improves enzyme activity; making the whole process less stressful on the pancreas." (Campion, 2010).

Ruminants and grazing animals did not evolve to process dry hard matter. Much of the energy in dry matter is wasted by the animal in the digestion and processing of feed. Feeding fresh sprouting fodder improves the digestive process so that the animal absorbs more energy and spends less energy on processing and producing waste. This net energy is then available for milk production, reproduction or weight gain.

The energy consumption of a typical dairy cow is as follows:

- 20% is used to generate heat
- 20% is used in 'system' maintenance
- 20% is used in energy production (milk, reproduction, growth)
- 40% goes towards waste (30% faecal, 5% gas, 5% urinary)

Consistency and Reliability
Considering changes in the climate consistent food availability and crop yields is becoming increasingly more important. A fodder system produces the same volume of fodder every day of the year, regardless of external climate conditions.

An intensive 7 -8-day growing cycle uses the combination of NFT in a highly controlled environment with specialized nutrients to produce a replicable feedstock that is rich in enzymes and vitamins.

Reduced Land Use
An automated fodder system can produce many times more fodder than the equivalent grassland…

"Utilising a fodder system allows farmers and landowners to look to alternative and potentially more profitable and sustainable used for their land. A typical 1-ton system produces up to 8 kg per metre squared of fresh sprouts every day. Approximately 365 tons per year is equivalent to 298 acres of grassland. Therefore, land can be used for other forms of revenue, or farmers can increase the size of their herd without needing more land to grow crops for food purposes." (H2o Farm, 2015).

Low Water Input
Due to automated water and nutrient delivery, as well as water recycling systems, hydroponic systems use100 times less than water than growing the same crop in a field, equivalent to saving 49,000 litres of water per ton of barley. (AHDB, 2018).

Environmental benefits

Reduced Carbon Footprint
In addition to reducing land and water use, an automated fodder unit cuts down vehicle transport, feed concentrates, pesticide use, improves air quality and can offtake heat and power from renewable sources to provide a more natural and environmentally friendly solution to feeding cattle.

Water saving
Another important benefit is the conservation of water. The use of NFT is at the core of this saving, with water constantly being re-circulated and then recycled. All types of farming are coming

under increased pressure from Governments to reduce water usage and protect water quality from crop-growing practices (Beharry-Borg, 2013).

Pesticide free
If the traditional method of farming is replaced by advanced methods like hydroponics then water is the main medium, which will carry the essential or tailored nutrients to the crops and no aerosolised or outdoor chemicals are necessary. Also, since soil is not being used, almost 80% of the possible pest attacks can are eliminated. (Aravind, 2018).

Dust free environment
Wheat dust-associated respiratory disease has been a major issue in the health of farmers and communities for several years. (Clancy, et al. 1991). The absence of dust during the hydroponics production process means less respiratory problems for both animals and human workers alike.

Reduction of methane production
Increasing atmospheric concentrations of methane has led scientists to examine its origin. Ruminant livestock can produce 250-500L of methane per day. Many factors influence methane emissions from cattle including,: level of feed intake, type of carbohydrates in the diet, feed processing, addition of lipids or ionophores in the diet, and alterations in the ruminal microflora. Methane emissions from cattle can be reduced by manipulating these factors. (Johnson & Johnson, 1995).

For example, by feeding livestock a more digestible fodder, digestion can take place more quickly, thus reducing the volume that is regurgitated and the associated methane production.

Case studies

Beef Cattle
Lipolysis and bio-hydrogenation in the rumen leads to the conversion of healthy poly-unsaturated fatty acids (PUFA) into unhealthy saturated fatty acids (SFS). Feeding a diet with elevated omega 3, which is found in fodder significantly reduces this rumenal conversion of PUFA to SFA. (Lanier & Corl, 2015).

In 2009, trials were conducted in Timaru, New Zealand, to compare weight gain in the winter between cattle fed a normal diet and cattle fed supplemental fodder. to compare weight gain of cattle fed

Conducted over 84 days on 100, approximately 10-month-old bulls.

Group one - 50 bulls, fed 28 days on normal pasture/hay then brought indoors for 56 days and fed on a diet of rape/hay.

Group two - 50 bulls, fed 28 days on pasture/hay plus fodder supplement at 3.75 kg per day, then indoors for 56 days on rape/hay plus fodder at 3.75 kg per day.

Conclusions were that the cattle in group two (fodder supplement) had a total live weight gain, over the period, that was 41% higher than those in group one.
In addition, the cost of feeding the treated group was 27% lower than the control group due to the lower cost of fodder production versus buying hay and rape.

Dairy cattle
Independent trials and studies point to improved milk yields and digestibility in dairy cattle fed fodder-based diets:

Ohio State University
Extended trials over 29 years indicate that dairy cattle fed freshly mown grass outperformed cattle fed the grass that was allowed to dry leading to a 28% increase in milk yield (Figure 2).

La Serenisima
A leading Argentine dairy farm conducted trials with 500kg Holstein cows.

Two groups of cows were fed normally for the first week, then in week 2 group one was fed with growing amounts of fresh green hydroponic sprouting barley.

Starting at only 2kg per cow the for the first 2 days the amount was increased by 2kg every 2 days until a maximum of 12kg per day was reached at the end of week 3. This 12kg per day was continued until the end of the test in week 8. The cows also had access to unlimited amounts of fodder.

The average difference in milk volume over the 5-week full test period was 11% higher in the fodder fed group. Likewise, the average milk fat difference was 23% higher in the fodder fed group.

Stanton University et al (1997) - Trials showed that animals grazing on fresh grass had higher levels of CLA (unsaturated fatty acid) in their milk and meat than those consuming conserved forage.

Elgersma, et al (2004) - Holstein Friesian dairy cows were fed pasture and then switched to a winter diet of maize/silage. The change in diet dramatically altered the FA composition of the milk. UFA decreased and SFA increased. The beneficial n-7FA rumenic acid + Vaccenic acid reduced by 80% within a week.

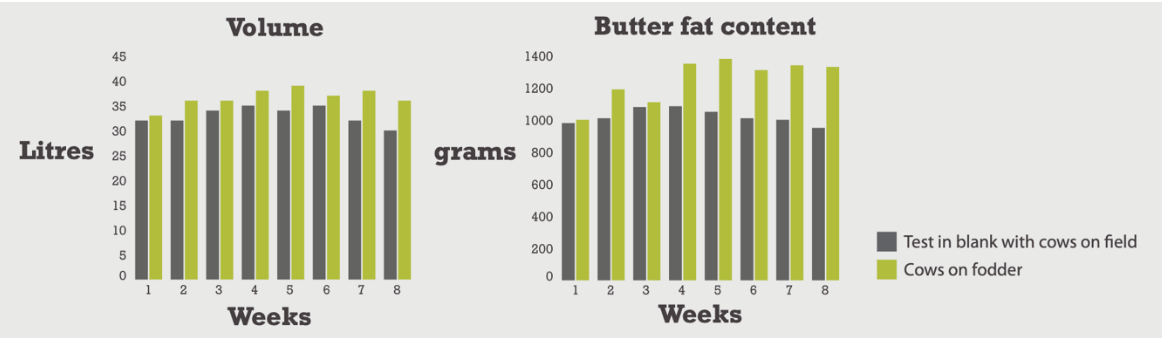

***Figure 2 – Milk quality from hydroponic fodder test group**

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