An Roinn Talmhaíochta,
Bia agus Mara
Department of Agriculture,
Food and the Marine

Research Stimulus Fund

Final Report

FEFAN: Feed evaluation for accurate nutrition

DAFM Project Reference No: 11/S/122

Start date: 01/06/2013

End Date: 31/05/2018

Principal Coordinator and Institution: Prof. Tommy Boland, University College Dublin
Email:tommy.boland@ucd.ie

Collaborating Research Institutions and Researchers:
University College Dublin: Prof. Tommy Boland, Prof. John O'Doherty, Assoc. Prof. Karina Pierce, Dr. Alan Kelly
Teagasc: Dr. Mark McGee, Dr. Siobhán Kavanagh, Dr. Aidan Moloney, Dr. Edward O'Riordan, Dr. Padraig O'Kiely

Please place *one* "x" below in the appropriate area on the research continuum where you feel this project fits

Basic/Fundamental → Applied → Pre Commercial

1	2	3	4	5	6 X	7

Please specify priority area(s) of research this project relates to from the National Prioritisation Research Exercise* (NRPE) report;

Priority Area (s)	**Sustainable Food Production and Processing**

Key words: dairy, beef, pigs, feedstuff

1. Rationale for Undertaking the Research

The world's human population has increased near fourfold in the past 100 years; it is projected to increase from 6.7 billion (2006) to 9.2 billion by 2050 (Nellemann et al., 2009). This is placing increased pressure on food production with food demand projected to increase between 70 and 100% (FAO, 2009). Meat consumption is projected to increase from 37.4 kg/person/year in 2000 to over 52kg/person/year by 2050 (FAO, 2006).

Annually Ireland produces approximately 5.5 million tonnes of milk, 559,000 tonnes of beef, and 265,000 tonnes of pig meat (Bord Bia, 2010). Nutrition is the key driver of animal production and accurately assessing the nutrient content of the feeds which animals consume is central to correct nutrition. Traditionally research had focused on analysing the chemical composition of feeds but the focus has shifted towards determining the nutrients which are available to the animal.

Approximately 90% of our land area is dedicated to the production of grazed and conserved grass (Rath and Peel, 2005).Conversion of cellulosic material into calories and protein that can be consumed by humans is the major advantage of ruminant production systems. Maximising the efficiency of this conversion is a key driver to developing a competitive advantage in the future. Much recent research (O'Donovan et al., 2010) has focussed on improving the quality of grazed pasture without any major attempts to capture the benefits in terms of available nutrients. This project will expand the knowledge base relating to the available nutrients present in grazed grass and the factors which influence this.

Annually 3.8 m tonnes of animal feed are produced in Ireland. Of this 2.5 m tonnes of by-product feeds are imported into the country. Feed tables (O'Mara, 1996) generally provide a single value for the nutrient contents of feeds but significant variation in nutrient content can exist for cereal grains and especially by-products. This project aimed to capture that variation and develop NIR equations which will allow for the rapid assessment of the nutrient content of feedstuffs.

This study supports more appropriate dietary formulation for improved animal productivity, product quality and reduced nutrient excretion, through a better description of the available nutrients in commonly used feedstuffs. As such the outputs of this project will aid in reaching the targets set out in Food Harvest 2020, will enhance the sustainability of production at farm level and will contribute to increasing food production in an efficient manner.

2. Research Approach

FEFAN represents a major collaborative approach by the main research stakeholders (UCD and Teagasc), key policy makers (DAFM) farmer representative bodies (IFA) and industry representatives (IGFA), targeted at optimising the nutrition of farm animals through developing the most up to date feed analysis and by product feed inclusion levels nationally. The research work incorporated a range of research approaches including laboratory and in vitro (Rusitec) analysis and in vivo animal based studies plus the widespread dissemination of research findings.

Approximately 232 concentrate feed samples were analysed, using a combination of wet chemistry, Near Infrared Spectroscopy and an Artificial rumen simulation technique. Individual feedstuffs, especially concentrate feed ingredients are rarely offered as whole diets, so the feeding of a combination of ingredients are their subsequent impacts on animal performance was assessed.

Performance of lactating pasture based dairy cows, finishing beef cattle and pigs was assessed in addition to the determination of the impact of ingredient type and composition on nutrient loss to the environment.

A new method for faecal collection for small ruminants was developed during the project, which removed the need for metabolism stalls in the conduct of feed digestibility studies. This altered the research approach used in Task 3 but not the experimental outputs.

As the number of different 'ethanol-specific' by-products imported into Ireland was subsequently much more limited than anticipated at the time of writing the project proposal, the range of feed ingredients under evaluation was expanded to include additional high-volume imported feedstuffs, and cereals, on a priority basis.

3. Research Achievements/Results

- *A data base comprising 232 individual concentrate feed samples and 250 grass/grazed forage samples developed*
- *Development of DE values for a range of feed ingredients used in monogastric diets*
- *Development of NE predictions for a range of feed ingredients used in monogastric diets*
- *Development of NE and PDI prediction values for a range of feed ingredients used in ruminant diets*
- *Pigs offered diets containing either low or high levels of by-products had an improved FCR compared to the basal diet. Carcass characteristics*
- *Animals offered diets with medium or high levels of by-products had higher carcass muscle content than the basal diet but by-product inclusion did not alter carcass weight, backfat depth, fat quality, lean meat percentage, kill out percentage and carcass ADG.*
- *Increasing by-production inclusion level in the diet of grower and finisher pigs reduces diet and nutrient digestibility*
- *Increasing by-product inclusion level in the diet increased nitrogen and phosphorous excretion by pigs but odour concentration or ammonia emissions were not affected*
- *Low quality wheat diets naturally contaminated with mycotoxins reduce performance, nutrient digestibility in pigs and influence gene expression in the gut. The inclusion of a mycotoxin binder improves performance, through improvements in feed intake and nutrient digestibility and modified gene expression of nutrient transporters and tight junction in the gut.*
- *High energy concentration diets (9.9 MJ/kg NE) improved FCR and increased the CATTD of DM, GE, DE and NE values. However, pigs offered the by-product diet at a high energy concentration had a poorer carcass NE efficiency compared to the by-product diet at a low energy concentration.*
- *Feed quality is a key parameter to determine pig performance. However, the addition of feed additives such as enzyme and mycotoxin binders may help to enhance feed quality.*
- *Increasing the inclusion levels of distillers grains, soya hulls and palm kernel meal in the concentrate of pasture fed dairy cows is possible without negatively impacting on milk production, rumen fermentation, the metabolic status of the dairy cow or excretion of N. This offers the opportunity for cost saving at farm level.*
- *By-products can be included at up to 95% of the concentrate fed to pasture based cows without impacting on feed intake, milk production or composition or nitrogen excretion.*

In the context of a rolled Barley/soyabean meal-based 'control' concentrate ration for beef cattle:

- *For growing 'weanling' cattle, soya hulls and citrus pulp can replace rolled barley in concentrate rations offered at relatively low levels (ca. 2 kg/day), as a supplement to high digestibility grass silage, without negatively affecting performance.*
- *For finishing cattle diets, citrus pulp can replace rolled barley in the ration at inclusion rates up to 400g/kg without negatively affecting performance when offered ca. 5.0 kg concentrate per day as a supplement to high digestibility grass silage.*
- *For growing cattle offered ca. 3.5kg/day of concentrate as a supplement to moderate digestibility grass silage, and finishing cattle offered ad libitum concentrates, the optimum inclusion level of soya hulls in a barley-based concentrate was ca. 200 g/kg.*

- *Dried corn gluten feed had a feeding value comparable to that of rolled barley/soya bean meal when offered as a supplement (ca. 5.0 kg/day) to high-digestibility grass silage.*
- *Maize dried distillers grains had a superior feeding value (based on dietary feed conversion ratio) to wheat dried distillers grains when the ration was offered as a supplement (3.5 kg/day) to grass silage or ad libitum. The optimal inclusion level of maize and wheat dried distillers grains in the concentrate was about 800 g/kg when the concentrate ration was offered as a supplement to moderate digestibility grass silage and, about 400 g/kg for maize, and 200g/kg for wheat, dried distillers when the ration was offered ad libitum.*
- *Palm kernel expeller meal can be included in a barley-based concentrate at up to 400 g/kg when offered as a supplement to moderate digestibility grass silage and up to 100 g/kg when offered ad libitum.*
- *Rolled oats can replace rolled barley in a concentrate supplement (ca. 5.0 kg/day) to high-digestibility grass silage without negatively affecting performance of finishing beef cattle; feeding oats had no effect on carcass fat score.*
- *Overall, the relative nutritive (and economic) value of by-product feed ingredients depends on their inclusion level in the ration, and the amount of concentrates fed. These findings imply that 'associative effects' between grass silage and concentrate feed ingredients have consequences for feed utilisation and thus, the nutritive value assigned to by-product feed ingredients.*
- *In general, if slaughtered at the same carcass weight/fatness, the composition of the diet does not greatly influence beef eating quality. Farmers therefore can choose the most cost-effective ingredients without compromising meat eating quality when compared to a barley/soyabean ration offered as a supplement to grass silage.*
- *In-vitro digestibility co-efficients of BP feeds were comparable to those found in vivo for maize distillers and wheat distillers. For higher fibre level BP in vitro digestibilities were reduced. Therefore, retention time in vivo must be taken into account when determining in vitro digestiblities in Rusitec and a suitable incubation time selected for individual feed types.*
- *On an individual basis and under in vitro conditions, soya hulls, palm kernel and distillers grains have been shown to produce a similar, and in some cases reduced, level of methane in comparison to traditional cereals and soybean meal.*
- *In RUSITEC continuous culture systems, different rumen fluid inoculum types (when sourced from divergent diets within animal species) has no effect on in vitro digestibility of by-product ingredients. Therefore, when examining in vitro digestibility, rumen inoculum type can be changed without affecting in vitro digestibility results. It also suggest that results obtained using differing rumen inoculum can be considered in the same way as results using pasture fed rumen inoculum.*
- *Higher levels of by-product in concentrate and addition of linseed oil both served to reduced methane production.*
- *Both the microbial population residing in the rumen and enteric methane, has been shown to be altered by the composition of the diet offered to ruminants. In vitro findings highlight the potential methane abatement potential of concentrates formulated from 95% BP ingredients, for grass based ruminant production systems.*
- *Data generated from our metataxonomic approach, suggests a favourable alteration to the rumen prokaryotic composition in favour of a potential reduction in the production of methanogenesis substrates, with the supplementation of our 95% BP formulated concentrate.*
- *Between two internationally recognised in-vitro techniques RUSITEC and Daisy incubations techniques, there were a strong relationship observed between their consistent ability to accurately predict the nutrient and digestibility co-efficient of a variety of cereal by-products and by-products formulated concentrate diets.*

- *There was a strong repeatability between growing and finishing pigs (phase of production) with both showing a similar decline in digestibility (dry matter, organic matter, N, GE and DE) in response to increased level by-products increased in the diet.*
- *Indicating that digestibility co-efficients for by-products are encouragingly consistent between growing and finishing pigs, despite the inherent animal variation in nutrient partitioning, body composition and growth trajectory between these life-phases.*
- *Across the ruminant species, for the individual by-product ingredients there was good consistency, with higher fibre byproducts typically reporting poorest digestibility for cattle and sheep.*
- *Interestingly though unlike the mongastric`s in which nutrient availability and digestion co-efficient for common byproducts appear to accurately depict the response in growing or finishing stages of the pig production cycle, for ruminants this is not so.*
- *Repeatability of nutritive value for the by-product is low between growing and finishing ruminant animal. Indeed, the relative nutritive value of by-product feed ingredients depends more on their inclusion level in the ration, the amount of concentrates fed, the forage and concentrate ratio. These associative effects' between grass silage and concentrate feed ingredients have consequences for feed utilisation and the nutritive value assigned to by-product feed ingredients for growing and finishing cattle.*
- *Individual feed ingredients and diet formulation were scanned by NIRS and incorporated into the NIR spectra. Prediction equations were derived for the various nutrient components.*

4. Impact of the Research

A summary of the tangible impact of the research project should be provided under the outcomes' and 'outputs' heading below. In addition, please provide a short narrative synopsis of the benefits / improvements the research has made to the area under investigation particularly as regards end users, e.g. industry, consumers, regulatory authorities, policymakers, the scientific community, etc

4(a) Summary of Research Outcomes

The FEFAN project was focussed on assessing feed and ingredient quality across a range of laboratory and animal feeding studies, with particular attention directed to the replacement of cereal grains in the diets of livestock with by-products and understanding the impacts on various emissions sources and animal performance. This work was underpinned by the development of a detailed feed database. The impacts of the project include

- Development of a feed database to support the commercial feed industry and farmers
- Design of diets (including max inclusion levels) for dairy cows, beef cattle and pigs which reduce the reliance on cereal grains in livestock production, while maintaining or enhancing animal performance and feed conversion efficiency
- The use of mycotoxin binders in low quality wheat diets fed to pigs improves nutrient digestion
- High level by-product inclusion and linseed oil inclusion in concentrate diets have the potential to reduce enteric methane emissions
- Further modification of in vitro methodologies to determine feed ingredient quality and digestibility.
- Data supporting the replacement of barley with oats in diets of beef cattle.
- The outcomes of this project continue to inform research activity to support the national livestock industry.

(i) Collaborative links developed during this research

- This research project strengthened existing links between the RPO's (UCD and Teagasc) and industry partners IGFA and IFA
- Additional collaborative links were developed with Trouw nutrition who collaborated on the development of NIRS equations
- This project has led to direct collaboration by Teagasc in the area of meat science with University College Cork (Drs Michael N. O'Grady and Joseph P. Kerry) and the University of Catania, Italy (Drs Giuseppe Luciano and Alessandro Priolo), through post-graduate, Saheed A. Salami.
- This project has led to direct collaboration by UCD and Teagasc with the Rumipredict research project (DAFM funded).
- Eight postgraduate students were trained through this project, each student had an external examiner which helped to develop academic networks of the principal scientists involved in this research

(ii) Outcomes where new products, technologies and processes were developed and/or adopted

- The research herein focussed on improved assessment of feed quality for more accurate nutrition of farmed livestock. An important outcome of this work is the development of feed tables for use in the rationing of ruminant and monogastric livestock.
- Guidelines for the incorporation of by-product feeds into ruminant and monogastric diets

(iii) Outcomes with economic potential .

Across all animal feeding studies the ability to replace cereal grains and soya-bean meal in the diets of ruminant and monogastric diets have the potential to improve the economic returns of primary producers. The magnitude of this economic improvement is dependent on both ingredient and product price

(iv) Outcomes with national/ policy/social/environmental potential

- Feeding by-product ingredients has the potential to reduce nitrogen excretion by pasture fed dairy cows.
- Furthermore, when tested in a rumen simulation technique diets with high levels of by-product ingredients reduce methane production, which has potential to be leveraged as a methane mitigation strategy in pasture based dairy production systems.
- Feeding high levels of by-products to pig diets did increase both nitrogen and phosphorous excretion so care is required in adoption of such production systems. However, the addition of feed additives such as enzyme and mycotoxin binders may help to enhance feed quality in pig diets.

4 (b) Summary of Research Outputs

Research outputs from this project include the publication of 14 peer review papers, 37 non-scientific publications and abstracts including those presented at conferences, at least 10 contributions to workshops and contributions to 11 undergraduate modules in UCD and one in DKIT.

(i) Peer-reviewed publications, International Journal/Book chapters.

- *Clarke, L. C., Sweeney, T., Duffy, S. K., Rajauria, G., & O' Doherty, J. V. (2019). The variation in hectolitre weight of wheat grain fed with or without enzyme supplementation influences nutrient digestibility and subsequently affects performance in pigs. Journal of Animal Physiology and Animal Nutrition, 103(2), 583-592. doi:10.1111/jpn.13038*
- *Condren, S. A., Kelly, A. K., Lynch, M. B., Boland, T. M., Whelan, S. J., Grace, C., et al. (2019). The effect of by-product inclusion and concentrate feeding rate on milk production and composition, pasture dry matter intake, and nitrogen excretion of mid-late lactation spring-calving cows grazing a perennial ryegrass-based pasture. J. Dairy Sci. 102, 1247–1256.*
- *L. C. Clarke, S. K. Duffy, G. Rajauria and J. V. O'Doherty (2018) Growth performance, nutrient digestibility and carcass characteristics of finisher pigs offered either a by-product or cereal based diet at two different concentrations of net energy. Animal Feed Science and Technology 242, 77-85*
- *L. C. Clarke, T. Sweeney, E. Curley, S. K. Duffy, G. Rajauria and J. V. O'Doherty (2017) The variation in chemical composition of barley feed with or without enzyme supplementation influences nutrient digestibility and subsequently affects performance in piglets. Journal of Animal Nutrition and Physiology 102 (3), 799-809*
- *L. C. Clarke, T. Sweeney, E. Curley, V. Gath, S. K. Duffy, S. Vigors, G. Rajauria and J. V. O'Doherty (2018) Effect of β-glucanase and β-xylanase enzyme supplemented barley diets on nutrient digestibility, growth performance and expression of intestinal nutrient transporter genes in finisher pigs. Animal Feed Science and Technology 238, 98-110*
- *L. C. Clarke, T. Sweeney, S. K. Duffy, S. Vigors, G. Rajauria and J. V. O'Doherty (2018) Mycotoxin binder increases growth performance, nutrient digestibility and digestive health of finisher pigs offered wheat based diets grown under different agronomical conditions. Animal Feed Science and Technology 240, 52-65*
- *Lenehan, C., Moloney, A.P., O'Riordan, E.G., Kelly, A., McGee, M. (2017). Comparison of rolled barley with citrus pulp as a supplement for growing cattle offered grass silage. Advances in Animal Biosciences 8, s1, 33-37.*
- *McGee, M. (2015). Feed efficiency in beef finishing systems. Irish Grassland Association Journal 49, 97-105.*
- *McGee, M., O'Riordan, E., Kenny D., Moloney A. (2018). Beef-cattle production: Feed-efficiency. Veterinary Ireland Journal 8, 239-242.*
- *Salami, S.A., O'Grady, M.N., Luciano, G., Priolo, A., McGee, M., Moloney A.P., Kerry, J.P. (2020). Concentrate supplementation with dried corn gluten feed improves the fatty acid profile of beef from steers offered grass silage. (Submitted - Journal of the Science of Food and Agriculture - under review).*
- *Salami, S.A., O'Grady, M.N., Luciano, G., Priolo, A., McGee, M., Moloney A.P., Kerry, J.P. (2020). Fatty acid composition, shelf-life and eating quality of beef from steers fed corn or wheat dried distillers' grains with solubles in a concentrate supplement to grass silage. Food Chemistry. (Submitted - Meat Science - under review).*
- *Salami, S.A., O'Grady, M.N., Luciano, G., Priolo, A., McGee, M., Moloney A.P., Kerry, J.P. (2020). Quality indices and sensory attributes of beef from steers offered grass silage and concentrate supplemented with dried citrus pulp. Meat Science, 168, (2020) 108181.*

- *Smith PE, Waters SM, Kenny DA, Boland TM, Heffernan J, Kelly AK. Replacing Barley and Soybean Meal With By-products, in a Pasture Based Diet, Alters Daily Methane Output and the Rumen Microbial Community in vitro Using the Rumen Simulation Technique (RUSITEC). Front Microbiol. 2020;11:1614. Published 2020 Jul 22. doi:10.3389/fmicb.2020.01614*
- *Whelan, S.J., Carey, W. Boland, T.M., Lynch, B.M., Kelly, A.J., Rajauria, G. and Pierce, K.M. 2017. The effect of by-product inclusion level on milk production, nutrient digestibility and excretion, and rumen fermentation parameters in lactating dairy cows offered a pasture-based diet. Journal of Dairy Science, 100: 1055-1062*

(ii) Popular non-scientific publications and abstracts including those presented at conferences

- *Boland, T., McGee, M., O'Doherty, J., Moloney, A., Kelly, A., Pierce, K. (2015). Evaluating by-products for inclusion in ruminant and monogastric diets. Proceedings: Advances in Knowledge & Technologies for Agriculture, Teagasc-UCD-ASA Conference, Tullamore, p6.*
- *Carey, B., Boland, T.M., Whelan, S.J., Rajauria, G. and Pierce, K.M. 2015. The effect of increasing level of by-product inclusion on milk production, milk composition, nutrient digestibility and nitrogen excretion in early lactation grazing dairy cows. in ADSA-ASAS Joint Animal Meeting. Journal of Dairy Science, 93, E-supplement S3, 853. Orlando, Florida, USA.*
- *Clarke L. C., Sweeney. T., McAlpine, P.O., Vigors. S. and O'Doherty, J. V. Mycotoxin binder increases growth performance and digestive health of finisher pigs offered wheat based diets grown under different agronomical conditions. Digestive Physiology of Pigs, August 2018.*
- *Clarke L. C., Sweeney. T., McAlpine, P.O., Vigors. S. and O'Doherty, J. V . Mycotoxin binder influences digestibility and nutrient transporters gene expression of pigs offered wheat based diets grown under different agronomical conditions. Digestive Physiology of Pigs, August 2018.*
- *Clarke, L. C., Curley, E., McAlpine, P.O. and O'Doherty, J. V. The effect of wheat quality and enzymes or mycotoxin binder inclusion on growth performance in pigs. European Federation of Animal Science, Belfast, Northern Ireland, 29th August – 2nd of September 2016.*
- *Clarke, L. C., Curley, E., McAlpine, P.O., Boland, T.M. and O'Doherty, J. V. The Effect of Barley Quality and Exogenous Enzymes Supplementation in Pig Diets on Growth Performance- Digestive Physiology of Pigs, Kliczków, Poland, May 19th – 21st May 2015.*
- *Clarke, L. C., Curley, E., McAlpine, P.O., Boland, T.M. and O'Doherty, J. V. Barley diets varying in chemical composition with or without enzymes can affect performance, nutrient digestibility and nutrient transporter gene expression in finisher pigs. British Society of Animal Science, April 2018.*
- *Clarke, L. C., Curley, E., McAlpine, P.O., Boland, T.M. and O'Doherty, J. V.Effect of β-xylanase and β-glucanase in wheat based diets achieved through different agronomical conditions on nutrient digestibility and growth performance in young pigs. British Society of Animal Science, April 2018.*
- *Clarke, L. C., Curley, E., McAlpine, P.O., Vigors. S. and O'Doherty, J. V. The effect of barley quality and exogenous enzymes supplementation on performance in finisher pigs. European Federation of Animal Science, Belfast, Northern Ireland, 29th August – 2nd of September 2016.*
- *Kelly, A.K., Boland, T.M. and Heffernan, J.S. 2017. Effects of by-product inclusion and linseed oil supplementation to a pasture based diet on methane production, diet utilization and ruminal fermentation parameters in the Rumen Simulation Technique (RUSITEC)* Journal of Animal Science*, Volume 95, Issue suppl. 4, 1,Pages 290, https://doi.org/10.2527/asasann.2017.592.*
- *Kelly, A.K., Boland, T.M. and Heffernan, J.S. Effect of rumen inoculum on diet utilization and ruminal fermentation parameters of commonly used By-product ingredients in the Rumen Simulation Technique (RUSITEC).* Journal of Animal Science*, Volume 95, Issue suppl. 4, 1. Pages 289. https://doi.org/10.2527/asasann.2017.591*

- *Kelly, A.K., Heffernan, J.S. Boland, M., Pierce, K.M. and Boland, T.M. 2018. Effect of by-product and linseed oil supplementation to a pasture based diet on methane production diet utilisation and ruminal fermentation. BSAS Annual Meeting 2018, Dublin Ireland, 9th -12th April 2018.*
- *Kelly, M., Moloney, A.P., Kelly, A., McGee, M. (2018). Intake, growth, carcass and selected meat quality traits of steers offered grass silage and supplementary concentrates with increasing levels of dried corn gluten feed. Advances in Animal Biosciences 9, (1), p150.*
- *Kelly, M.J., Moloney, A.P., Kelly, A., McGee, M. (2017). Replacement of rolled barley with citrus pulp in a concentrate supplement for finishing beef cattle offered grass silage. Journal of Animal Science 95, Suppl. 4, 295.*
- *Lenehan, C., Moloney, A.P. O'Riordan, E.G., Kelly A., McGee, M. (2016). Comparison of rolled barley with citrus pulp as a supplement for growing cattle offered grass silage. Book of Abstracts, 67th Annual Meeting of European Federation for Animal Science (EAAP), Belfast UK, p142.*
- *Magee, D., Moloney, A.P., Kelly, A., O'Riordan E.G., McGee, M. (2016). Inclusion of palm kernel expeller meal in barley-based concentrates for beef cattle. Book of Abstracts, 67th Annual Meeting of European Federation for Animal Science (EAAP), Belfast UK, p669.*
- *Magee, D., Moloney, A.P., Kelly, A., O'Riordan, E.G., McGee, M. (2015). Effect of replacing barley with increasing levels of wheat dried distillers grains on intake, growth and carcass traits of beef cattle. Proceedings: Agricultural Research Forum, Tullamore, p75. ISBN: 978-1-84170-615-3.*
- *Magee, D., Moloney, A.P., Kelly, A., O'Riordan, E.G., McGee, M. (2015). Replacement of barley with increasing levels of maize dried distillers grains: intake, growth and carcass characteristics of beef cattle. Proceedings: Agricultural Research Forum, Tullamore, p80. ISBN: 978-1-84170-615-3.*
- *Magee, D., Moloney, A.P., Kelly, A., O'Riordan, E.G., McGee, M. (2015). Intake and performance of beef cattle offered barley-based concentrates with increasing inclusion levels of soya hulls. Proceedings: Agricultural Research Forum, Tullamore, p81. ISBN: 978-1-84170-615-3.*
- *McGee, M. (2015). Feed efficiency in beef finishing systems. Irish Grassland Association – Quarterly Newsletter - Issue No. 30 - Winter 2015. p20-22.*
- *McGee, M. (2016). Aspects of Feed Efficiency in Beef Production. Proceedings: Society of Feed Technologists, Ruminants Conference, Coventry, UK, 9 pages.*
- *McGee, M., Kelly, M., Kelly, A., Moloney, A.P. (2018). Comparison of rolled barley and oats as supplements to grass silage for finishing beef cattle. Advances in Animal Biosciences 9, (1), p226.*
- *McGee, M., Kelly, M., Moloney, A. (2018). "Value of citrus pulp" [Citrus pulp compared to rolled barley as a supplement for finishing cattle offered grass silage]. Teagasc Beef Advisory Newsletter, Research Update, March 2018.*
- *McGee, M., Lenehan, C., O'Riordan, E., Moloney, A. (2016). 'Comparing feed ingredients' [Comparison of rolled barley with citrus pulp as a supplement for growing cattle offered grass silage]. Teagasc Beef Advisory Newsletter, Research Update, May 2016.*
- *McGee, M., Magee, D., Moloney, A., O'Riordan, E. (2015). Replacement feeds in beef cattle: intake, growth and feed efficiency. Teagasc Beef Advisory Newsletter, Research Update, September 2015.*
- *McGee, M., Moloney, A. (2019). Characterisation of the feeding value of imported by-product feedstuffs for beef cattle. Teagasc, Technology Update, Project No. 6377, 4 pages.*
- *McGee, M., Moloney, A.P. (2018). "Concentrate on oats" [Comparison of rolled barley and oats as supplements to grass silage for finishing beef cattle]. Teagasc Beef Advisory Newsletter, Research Update, August 2018.*
- *McGee, M., O'Riordan, E., Moloney, A. (2016). 'Finishing with palm kernel' [Inclusion of palm kernel expeller meal in barley-based concentrates for beef cattle]. Teagasc Beef Advisory Newsletter, Research Update, August 2016.*

- *McGee, M., O'Riordan, E., Moloney, A. (2016). Concentrate feeding for growing and finishing cattle. In: Beef 2016 'Profitable Technologies', Tuesday, 5th July 2016, Teagasc, Grange, Dunsany, Co. Meath, p56-59, Eds. M. McGee and P. Crosson, ISBN: 978-1-84170-627-6.*
- *McGee, M., O'Riordan, E., Moloney, A. (2016). Concentrate feeding for beef cattle. TResearch 11, (2) Summer 2016, p26-27.*
- *McGee, M., O'Riordan, E., Moloney, A. (2017). Concentrate feed ingredients for growing finishing cattle. In: 'Planning for Healthy profits', Teagasc National Beef Conference, 17 October, Tullamore, Co. Offaly. 32-39.*
- *McGee, M., O'Riordan, E., Moloney, A. (2018). Concentrate feeding and feed ingredients for growing-finishing cattle In: BEEF 2018, '€nhancing Knowledge', Tuesday, 26th June 2018, Teagasc, Grange, Dunsany, Co. Meath, p152-155. Eds. M. McGee and A. Moloney, ISBN: 978-1-84170-646-7*
- *Moloney, A., McGee, A., O'Riordan, E., O'Sullivan M., Kerry, J. (2018). On-farm influences on the eating quality of beef In: BEEF 2018, '€nhancing Knowledge', Tuesday, 26th June 2018, Teagasc, Grange, Dunsany, Co. Meath, p164-167. Eds. M. McGee and A. Moloney, ISBN: 978-184170-646-7*
- *S.A. Condren, S.J. Whelan, T.M. Boland, G. Rajauria, S. Kirwan, M.B. Lynch and K.M. Pierce. 2016. The Effect of By-Product Inclusion and Concentrate Feeding Level on Milk Production and Composition, Pasture Dry Matter Intake, Body Weight and Body Condition Score of Mid-Late Lactation Spring Calving Grazing Dairy Cows. - American Society of Animal Science*
- *Salami, S.A., O'Grady, M.N., Luciano, G., Priolo, A., Onakuse, S., McGee, M., Moloney A.P., Kerry, J.P. (2018). Inclusion of dried corn gluten feed in a concentrate supplement for grass silage-fed steers improves the fatty acid profile of beef. Journal of Animal Science 96, Suppl. 3, 62–63.*
- *Salami, S.A., O'Grady, M.N., Luciano, G., Priolo, A., Onakuse, S., McGee, M., Moloney A.P., Kerry, J.P. (2018). Fatty acid composition and antioxidant potential of beef from steers fed corn or wheat dried distillers' grains in a supplement to grass silage. Journal of Animal Science 96, Suppl. 3, 284.*
- *Smith P. E, Heffernan J., Waters S. M., Boland T. M., Kenny D. A., Kelly A. K. 2019. High by-product inclusion rate to pasture diets reduces methane production and alters the rumen microbiome. British Society of Animal Science, Climate Change and Livestock: What Next? Workshop. London, UK. 2nd December 2019.*
- *Smith P. E, Heffernan J., Waters S. M., Boland T. M., Kenny D. A., Kelly A. K. 2019. High by-product inclusion rate to pasture diets reduces methane production and alters the rumen microbiome. Proceedings from the 7th GGAA – Greenhouse Gas and Animal Agriculture Conference, Iguassu Falls, Brazil. August 4-8th, 2019. P102.*

(iii) National Report

N/A

(iv) Workshops/seminars at which results were presented

- *Teagasc, 'In-service Training': November (2019).*
- *QQI 'Cattle Nutrition Course': Teagasc, Grange – June (2019)*
- *Teagasc, National Beef Open Day: BEEF 2018, '€nhancing Knowledge', Teagasc, Grange, Co. Meath: June (2018)*
- *'ConnectEd' - Feed Trade Meeting: Teagasc Enniscorthy: January (2018)*
- *FETAC 'Cattle Nutrition Course': Teagasc, Grange - October (2017)*
- *Teagasc, National Beef Open Day: BEEF 2016 'Profitable Technologies', Teagasc, Grange, Co. Meath: July (2016)*

- *FETAC 'Cattle Nutrition Course': Teagasc, Grange - October (2016)*
- *Agricultural Science Association (ASA) – 'Beef Nutrition Master Class': Teagasc, Grange - November (2016)*
- *'FEFAN Update' - Workshop for IGFA Technical personnel: Lyons Estate, UCD, 16 September (2015).*
- *Teagasc, 'In-service Training': October (2015).*

(v) Intellectual Property applications/licences/patents

(vi) Other

Undergraduate education

The results of this project were included in a number of modules in the UCD B.Agr.Sc program including

- Animal Nutrition I
- Animal Nutrition II
- Ruminant Animal Production
- Non-Ruminant Animal Production
- Dairy Production
- Beef Production
- Advanced Dairy
- Advanced Beef
- Advanced Swine Production
- Introduction to Animal Science
- Principles of Animal Science
- Beef Cattle Production - Nutrition & Feed Efficiency: Lecture to DKIT M.Sc. Agricultural Biotechnology: November (2017) Delivered by Dr. Mark McGee

5. Scientists trained by Project

Total Number of PhD theses: _1___

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

Louise Clarke (2018). The effects of feed quality and feed additives in pig nutrition.

Total Number of Masters theses: __7__

Please include authors, institutions and titles of theses and submission dates. If not submitted please give the anticipated submission date

- Mark Boland (2017). The potential of Linseed oil to mitigate methane and improve performance in ruminant animals.
- David Magee (2015). Feeding value of by-product feedstuffs offered to beef cattle as a supplement to grass silage or ad libitum. M.Agr.Sc. Thesis UCD/NUI. 152 pages.
- Michael Kelly (2017). Feeding value of dried corn gluten feed and dried citrus pulp offered to beef cattle as a supplement to grass silage. M.Agr.Sc. Thesis. UCD/NUI. 114 pages.

- Billy Carey (2015). The effect of increasing levels of by-products on milk production and composition, nutrient digestibility and nutrient excretion in early-mid lactation dairy cows at pasture.
- Sarah Condren (2017). The Effect of By-Product Inclusion Level and Concentrate Feeding Rate on Pasture Dry Matter Intake, Milk Production and Composition and Nitrogen Excretion of Mid-Late Lactation Spring Calving Dairy Cows Grazing a Perennial Ryegrass-Based Pasture.
- Mícheál Paul O'Leary (2015). Response in grower-finisher pigs to diets containing incremental levels of by-products in the diet.
- John Heffernan (2018). Determination of In vitro digestibility, fermentative outputs and methane production of commonly used by-product feeds using the Rumen Simulation Technique (Rusitec).

6. Permanent Researchers

Institution Name	Number of Permanent staff contributing to project	Total Time contribution (person years)
UCD	Tommy Boland	0.6
UCD	Karina Pierce	0.3
UCD	John O'Doherty	0.3
UCD	Alan Kelly	0.3
Teagasc	Mark McGee	0.88
Teagasc	Edward Mulligan	0.60
Teagasc	Aidan Moloney	0.18
Teagasc	Margaret Murray	0.01
Total		**3.17**

7. Researchers Funded by DAFM

Type of Researcher	Number	Total Time contribution (person years)
Post Doctorates/Contract Researchers	2	2.55
PhD students	1	4.31
Masters students	7	12.05
Temporary researchers	3	0.73
Other		
Total	**13**	**19.64**

8. Involvement in Agri Food Graduate Development Programme

N/A

9. Project Expenditure

Total expenditure of the project:	€ 882,067.59
Total Award by DAFM:	€ 802,067.59
Other sources of funding including benefit in kind and/or cash contribution(specify): Cash contribution from IGFA and IFA	€ 80,000.00

Breakdown of Total Expenditure

Category	UCD	Teagasc	Name Institution 3	Name Institution 4	Total
Contract staff	69208.24				69208.24
Temporary staff	22767.73				22767.73
Post doctorates					
Post graduates	287769.06	77086.53			364855.59
Consumables	148045.68	27412.22			175457.90
Travel and subsistence	15399.60	5842.02			21241.62
Sub total					
Durable equipment	2277.19				2277.19
Other	42200				42200
Overheads	150957.09	33102.23			184059.32
Total					882067.59

10. Leveraging

Summarise any additional resources'/funding leveraged by this award from other sources e.g. Additional Staff, National/EU funding secured, EI Commercialisation Fund, etc.

- This project has led to direct collaboration by Teagasc in the area of meat science with University College Cork (Drs Michael N. O'Grady and Joseph P. Kerry) and the University of Catania, Italy (Drs Giuseppe Luciano and Alessandro Priolo), through post-graduate, Saheed A. Salami.
- This project has led to direct collaboration by UCD and Teagasc with the Rumipredict project
- *Relationships developed during this project continue to be leveraged at the date of report submission through the submission of two enterprise Ireland Innovation Partnership projects

11. Future Strategies

Outline development plans for the results of the research.
A comprehensive feed database will be distributed to the Irish feed industry through the Irish Grain and Feed Association.