<table>
<thead>
<tr>
<th><strong>Title</strong></th>
<th>Biosystems Engineering Research Review 20</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Publication date</strong></td>
<td>2015-05</td>
</tr>
<tr>
<td><strong>Publisher</strong></td>
<td>University College Dublin. School of Biosystems Engineering</td>
</tr>
<tr>
<td><strong>Item record/more information</strong></td>
<td><a href="http://hdl.handle.net/10197/6758">http://hdl.handle.net/10197/6758</a></td>
</tr>
</tbody>
</table>
FOREWORD

The Nineteenth Annual Research Review describes the ongoing research programme in the School of Biosystems Engineering at University College Dublin from over 79 researchers (10 academic staff, 2 technicians, 8 postdoctoral researchers and 59 postgraduates). The research programme covers three focal areas: Food and Process Engineering; Bioresource Systems; and Bioenvironmental Engineering. Each area is divided into sub-areas as outlined in the Table of Contents which also includes the name of the research scholar (in bold); the research supervisor(s); the title of the research; the nature* of the research programme; and the research sponsors. It also includes the noting of four awards for presentational excellence at the Nineteenth Annual Biosystems Engineering Research Seminar held in University College Dublin on Thursday 12th March 2015.

The four Appendices in the Review provide:

- a listing of research projects in progress which were not included in the Review;
- profiles of Postdoctoral Research Scholars;
- a photographic record of postgraduate students; and
- a photographic record of the full-time staff who assisted in project supervision and administration.

The Editors gratefully acknowledge the dedicated work of the individual research scholars, their research supervisors and the financial support of research sponsors. Suggestions as to how future editions might be improved in presentation, style or content would be greatly appreciated. A copy of this book is available to download from the UCD Research Repository at: http://researchrepository.ucd.ie

ENDA CUMMINS and TOM CURRAN 20th May 2015

*MEngSc1, MSc1, MAgrSc1 = Research Masters (Mode 1)
MEngSc2, MSc2 = Taught Masters (Mode 2)
# TABLE OF CONTENTS

| Title Page | i |
| Foreword  | ii |
| Table of Contents | iii |

## FOOD and PROCESS ENGINEERING

### Imaging/Computer Vision

**Mukherjee S** and Gowen A. Chemical imaging of solvent cast poly-l-lactic acid (PLLA) and poly-3-hydroxybutyrate (P3HB) thin film blend using mid infrared imaging-chemical imaging (MIR-CI) (MSc). European Research Council Starting Grant programme.  

Zhi Y and Gowen A. Chemometrics: multivariate curve resolution with hyperspectral imaging data (MSc2).  

**Su WH**, He HJ and Sun DW. Application of hyperspectral imaging technique for measurement of external defects of potatoes (PhD). University College Dublin (UCD) and the China Scholarship Council (CSC).  

**Xu JL**, Riccioli C and Sun DW. Application of near-infrared hyperspectral imaging for non-destructive determination of 2-thiobarturic acid (TBA) value in atlantic salmon (*salmo salar*) fillets (PhD). CSC-UCD Scholarship Scheme.  

**Pu YY** and Sun DW. Moisture content distribution in mango slices during microwave-vacuum drying using NIR hyperspectral imaging (PhD). CSC-UCD Scholarship Scheme.  

**He HJ** and Sun DW. Visualization of pseudomonas loads of salmon flesh using near-infrared hyperspectral imaging technique (PhD). CSC-UCD Scholarship Scheme.  

### Risk Assessment/Traceability


## iii
von Westerholt F and Butler F. A numerical approach to interpreting uncertainty associated with quality control for *cronobacter* spp. in powdered infant formula (PhD). Food Institutional Research Measure (FIRM) administered by the Irish Department of Agriculture, Food and the Marine.

**Food Processing/Process Analytical Technology**

McHugh E and O’Donnell C. Separation of dairy powders by near infrared spectroscopy using unsupervised pattern recognition methods (ME). **Joint Taught Masters Award for Best Seminar Presentation.**

Meehan J and Cummins E. Public and animal health risks associated with spreading the products of anaerobic digestion (MEngSc2).

Pathak A and O’Donnell C. Authenticity verification of an alcoholic beverage using NIR spectroscopy (MEngSc2). **Joint Taught Masters Award for Best Seminar Presentation.**

Sivaraman A and Cummins E. Exposure assessment of acrylamide for Irish consumers (MEngSc2).

Sridhar A and O’Donnell C. Process analytical technology in milk powder manufacture (MEngSc2).


Kadam S. and O’Donnell C. Optimization and characterization of ultrasound assisted extraction of phlorotannins from *a. Nodosum* (PhD). IRCSET.

**ENERGY & THE ENVIRONMENT**

**Sustainable Energy**

Arulmozhi V, Devlin G and McDonnell K. An Energy Audit of the Agriculture Building in University College Dublin to Reduce Greenhousehouse Gas Emissions and Increase Sustainability (MSc2).

Convery B and Patrick Grace P. Assessing the potential impacts of climate change on the wind energy resource of Ireland (MSc2).

Koshkarbayev M and McDonnell K. A feasibility study of powering adjacent communities from decentralised renewable energy hubs in Kazakhstan (MSc2).
Table of Contents (continued)

**Kumar A** and McDonnell K. Pulsed electric field pretreatment of anaerobic digestion feedstock to increase biogas yield (*MSc2*). 73

**Martin L** and McDonnell K. The technical and economic feasibility of siting a pilot scale anaerobic digester at UCD (*MSc2*). 77

**Nolan M** and Cummins E. An assessment of the public perception of hydraulic fracturing in Ireland through quantitative research (*MSc2*). 81

**O’Sullivan N**, McDonnell K and Lynch D. Integration of a biorefinery with a local community: A feasibility study (*MSc2*). 85

**Tashi T**, Grace P. Feasibility of sizing a new chp plant in university college Dublin and to assess economic and environmental impacts of different chp technologies (*MSc2*). 89

**Environmental Technology/Modelling**

**Goyal R** and Gowen A. Food waste valorisation: production and characterisation of biopolymer films from milk derived protein (*MSc2*). 93

**Karmarkar M**, Bolger P and Curran T. Evaluating Irish environmental research 1991-2015 (*MSc2*). 97

**Kale AP**, Kelleghan D and Curran TP. Use of biomonitors in the detection of ammonia emissions from intensive agricultural units in county Cork (*MSc2*). 101

**McMahon H**, Kelleghan D and Curran TP. The validity of the scail agriculture model as a screening tool in Ireland (*MSc2*). **Joint Taught Masters Award for Best Seminar Presentation.** 105

**Kelleghan D**, Ward S Hayes E, Everard M, and Curran TP. Using geographical information systems to screen special areas of conservation against atmospheric ammonia (*PhD*). STRIVE as administered by the Environmental Protection Agency. 109

**Chicampo A**, Kelleghan D, Gillespie GD and Curran TP. Screening NH3 emissions from intensive agriculture in relation to natura 2000 sites in Ireland and Spain. STRIVE as administered by the Environmental Protection Agency. 113

**De Wulf C**, Kelleghan D, Curran TP. Sentivity of Irish grasslands to atmospheric nitrogen from intensive pig and poultry farms. STRIVE as administered by the Environmental Protection Agency. 117

**Meegan A** and Cummins E. Human health risk assessment of lead found in tap water in Ireland (*MSc2*). 121

**Vinagre-Sendino J** and Grace P. An analysis of the trends in Irish precipitation patterns (*MSc2*). 125
<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Institution</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wallace T, O'Dwyer M and Curran TP</td>
<td>Development of a national strategy for recovery and utilisation of fat, oil and grease (FOG) waste from food service outlets (FSOs) (MSc1). Irish Research Council and Noonan Services Group as part of the Employment Based Postgraduate Research Programme.</td>
<td>129</td>
<td></td>
</tr>
<tr>
<td>Gibbons D, O'Dwyer M and Curran TP</td>
<td>Assessing dublin city council’s fat, oil and grease (fog) programme through grease trapping system (gts) installation and maintenance. Irish Research Council and Noonan Services Group as part of the Employment Based Postgraduate Research Programme. Joint Winner Research Masters Award for Best Seminar Presentation.</td>
<td>133</td>
<td></td>
</tr>
<tr>
<td>O'Flaherty E and Cummins E</td>
<td>Identification of antimicrobial resistant organisms in surface water ecosystems and risk assessment strategies for their control (PhD) Environmental Protection Agency and the Water JPI programme.</td>
<td>137</td>
<td></td>
</tr>
<tr>
<td>Clarke R and Cummins E</td>
<td>A quantitative risk ranking of classic and “emerging contaminants” in biosolids and risk to human health (PhD). Irish EPA for the funding of this project under the STRIVE Programme.</td>
<td>141</td>
<td></td>
</tr>
<tr>
<td>Liu R and Holden N</td>
<td>The environmental impact of pasteurization and UHT in dairy processing (PhD). CSC-UCD Scholarship Scheme.</td>
<td>145</td>
<td></td>
</tr>
<tr>
<td>Chen WH and Holden NM</td>
<td>Economic tools for sustainability assessment (PhD). Smart Integrated Livestock Farming (SILF) project, under ERA-NET.</td>
<td>149</td>
<td></td>
</tr>
<tr>
<td>Murphy E, Curran T, Holden N and Upton J</td>
<td>Water required for grass growth on irish dairy farms (PhD). Teagasc Walsh Fellowship Scheme and the support of the Carbery Greener Dairy Farms project.</td>
<td>153</td>
<td></td>
</tr>
<tr>
<td>Oldfield T and Holden NM</td>
<td>Quantifying the potential environmental saving due to wasted food minimisation - A case study of Ireland (PhD). Irish Research Council under the Government of Ireland scheme. Senior PhD Joint winner (Yr 3-4) Award for Best Seminar Presentation.</td>
<td>157</td>
<td></td>
</tr>
</tbody>
</table>
Table of Contents (continued)

BIOENVIRONMENTAL ENGINEERING

Soil and Water Management

McKiernan D, Emmet-Booth J. and Holden N. Visual soil structure assessment of the dairy unit at UCD Lyons research farm (MSc2). 161


Dunne K, Holden N and Daly K. The application of nir and mir for the prediction of soil phosphorus dynamics in agricultural soils (PhD). Teagasc Walsh Fellowship Scheme. 168

Emmet-Booth JP, Forristal PD, Fenton O and Holden N. Selection of suitable visual soil examination and evaluation techniques for use in Irish grasslands (PhD). Irish Department of Agriculture, Food and the Marine, Research Stimulus Fund. 172

APPENDICES

Appendix 1 Listing of research projects in progress which have not been included in the Research Review. 176

Appendix 2 Profiles of Postdoctoral Research Scholars (Drs Devlin, Esquerre, Everard, Farrell, O’Brien, Riccioli, Walsh. 177

Appendix 3 Biosystems Engineering, UCD: Postgraduate School 2014/2015 as photographed by Sean Kennedy. 184

Appendix 4 Biosystems Engineering UCD: Staff Complement 2014/2015 as photographed by Sean Kennedy. 188
CHEMICAL IMAGING OF SOLVENT CAST POLY-L-LACTIC ACID (PLLA) AND POLY-3-HYDROXYBUTYRATE (P3HB) THIN FILM BLEND USING MID INFRARED IMAGING-CHEMICAL IMAGING (MIR-CI)

Sindhuraj Mukherjee, Aoife Gowen
School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland

Abstract
This paper describes the application of Mid Infrared Chemical Imaging (MIR-CI) to rapidly and non-destructively characterise biopolymers, specifically solvent cast polymeric films of Poly-L-Lactic Acid (PLLA), a naturally derived polymer and Poly-3-hydroxybutyrate (P3HB), a product of microbial fermentation. An optimised solvent casting protocol to prepare thin films of PLLA, P3HB and a 50:50 blend of PLLA/P3HB is presented and spatial imaging of these films using MIR-CI is discussed. The paper ends with a discussion on future experiments to further understand behaviour of these films.

Introduction
Polymers derived from renewable sources with well characterised biodegradation are of great interest to polymer chemists due to fluctuations in petroleum costs and availability (Yu et al. 2006). Poly-L-Lactic Acid (PLLA) and Poly-3-hydroxybutyrate (P3HB) represent a class of biopolymers derived from renewable sources. Environment friendly, thin films created from different blends of these polymers allow one to compensate for disadvantages of a pure polymer component film. For example, films made of Poly-L-Lactic Acid (PLLA) suffer from poor mechanical strength, and are blended with a certain percentage of Poly-3-hydroxybutyrate (P3HB) to increase its flexibility and improve mechanical strength depending on the application (Furukawa et al. 2007).

Many established characterisation methods for such blends exist, but few offer the advantages of non-destructivity of samples and the ability to spatially visualise polymer component distribution (Crompton 2009). Mid Infrared Chemical Imaging (MIR-CI) is a combination of Fourier-transform infrared spectroscopy and digital imaging, which allow acquisition of reflectance or transmission spectra from multiple points on a sample, which could be a liquid or solid, in one go, without significant sample preparation. This represents a major improvement over conventional point spectroscopy, since spectra an area of 500um$^2$ on the sample can be captured within a few seconds as opposed to collection of data from separate points or features on a sample. These spectra can then be analysed using chemometric techniques (Principal Component Analysis, Multivariate Curve Resolution) to visualise component distribution in a blend.

Solvent casting is one of the simplest scalable methods of polymer film preparation and for this reason, is widely used in research (Siemann 2005). In this paper, a simple solvent casting protocol was developed to create thin films of PLLA, P3HB and 50:50 blend of PLLA and P3HB. Preliminary analysis of the resulting mid-infrared spectra and component distribution of the blend is presented. The objective of this study is to look at the application of Mid Infrared Chemical Imaging (MIR-CI) to rapidly and non-destructively characterise biopolymers

Materials and Methods

Solvent Casting
P3HB (molecular weight (Mw) = 650,000g/mol) and PLLA (Mw =24000 g/mol) were purchased from Sigma Aldrich (3050 Spruce Street, Saint Louis, MO 63103, USA).
Numerous optimisation processes including different kinds of substrates (Aluminium dish, glass slide, glass slides covered with foil), different pouring techniques (pouring directly from a beaker, or the use of a syringe), combinations of stirring speeds, ideal temperature-time measurements and different drying processes (air drying, oven drying, vacuum oven drying) were tested to produce films of desirable quality. The samples discussed here were 1% by mass polymer solutions of pure PLLA, pure P3HB and a 50:50 blend of PLLA and P3HB, made by dissolving the polymers in hot chloroform along with vigorous stirring at 60°C, 700rpm for 12 minutes. Once dissolved, 2ml syringes were used to cast the solution onto clean glass slides, and these were left to dry overnight at room temperature. Small sections (2mm x 2mm) of these films were cut and loaded on a sample stage of the instrument and imaged.

**Figure 1**: (a) depicts the chemical structure of P3HB, (b) depicts the chemical structure of PLLA and (c) shows a typical solvent cast film of 1% by mass Poly-3-hydroxybutyrate (P3HB)

**Mid Infrared Chemical Imaging (MIR-CI)**

A Thermo Scientific™ Nicolet™ iNTM10 Infrared Microscope offering a fixed 10x magnification, fitted with a Mercury-Cadmium-Tellurium (MCT) detector, capable of imaging in the 7800–650 cm⁻¹ range, with LED illuminators, was employed to image the thin film samples. A germanium crystal (refractive index = 4) was used to collect spectra in Attenuated total reflectance (ATR) mode. Transmission spectra for three films (pure PLLA, pure P3HB, and a 50:50 blend) were collected at for a 450x350mm² area of the sample at 10um spatial resolution, 4cm⁻¹ spectral resolution with a scan time of approximately 60 seconds each. Background spectra for each sample was collected using air as reference before every measurement.

**Data Processing**

ATR data for each film sample were divided by their respective background spectra before converting to absorbance values for the entire scanned area. Spectra from pure PLLA and pure P3HB films were extracted from the blend to prepare correlation maps depicting localised spots of each component in the blend. Omnic™ Picta™ was used to collect data and process it.

**Results and Discussion**

Absorbance spectra from a selected point on the imaging area of the 3 films provides the basis for constructing correlation maps. PLLA and P3HB reference peaks were identified based on (Kister et al. 1998) and (Vogel et al. 2008). Figure 2 shows the absorbance spectra of the three films, and based on a simple observation, peaks at 1753cm⁻¹(C=O stretch), 1183cm⁻¹(C-O-C asymmetric stretch) and 1086cm⁻¹(C-O-C symmetric stretch) are visible in both PLLA and blend spectra, whereas, peaks at 1721cm⁻¹(C=O stretch), 1277cm⁻¹(also a C=O stretch)
and 979 cm\(^{-1}\) (\(-\text{C-H bend}\)) are found in the P3HB and blend spectra. This confirms the presence of both polymer components in the blend. The blend image spectra at all locations in the image were correlated to the pure component spectra and distribution of each component is visualised as correlation maps in Figure 3 and Figure 4 for regions of PLLA and P3HB on the blend respectively.

**Figure 2:** This graph depicts the Absorbance spectra for a pure PLLA film, pure P3HB film and the 50:50 (PLLA, P3HB) blend at any random point on the 350x450 mm\(^2\) sampling area.

**Figure 3(a):** PLLA correlation with blend. **Figure 3(b):** P3HB correlation with blend.

**Figure 3:** (a) Regions in red show concentrations of PLLA, and in (b), regions in red show a maximum likelihood of P3HB. Both concentration maps are correlating spectra from the blend image with pure spectra of PLLA and P3HB respectively.
Conclusions
In this paper, we demonstrate that, blends of solvent cast polymer films can be characterised quickly using MIR Chemical Imaging. Spectral correlation maps allow us to visualise the distribution of pure components present in the blend. Such qualitative analysis can be combined with chemometric analysis methods to predict concentrations of pure components on an imaged area by simply using blend concentrations. In the future, we plan to conduct more experiments to further characterise behaviour of such solvent cast films using chemical imaging, contact angle measurements, depth profiling etc, under different environmental conditions such as change in temperature, chemical attack and enzymatic degradation to understand the process of degradation.

Acknowledgements
The authors acknowledge funding from the EU FP7 under the European Research Council Starting Grant programme.

References


CHEMOMETRICS: MULTIVARIATE CURVE RESOLUTION 
WITH HYPERSPECTRAL IMAGING DATA

Yichi Zhi and Aoife Gowen
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland

Abstract

Multivariate curve resolution (MCR) is a chemometric method that can be applied to analyse the composition of multicomponent samples, such as hyperspectral images. In this study, hyperspectral data was simulated, by creating mixtures of different percentages of PVC and PET spectra. MCR was applied to retrieve the pure component spectra. The effect of adding noise to the hyperspectral data on MCR performance was investigated.

Introduction

Samples often contain many components to be simultaneously analysed or a few interesting analytes in the presence of many other chemical interferences. More complex instrumentation is needed to cope with these systems in an efficient way and, equally needed are tools to handle and interpret the information obtained. Hyperspectral imaging is one example. MCR can be applied to analyse the spectra of mixed sample material and find out the raw material that are used to make these samples (Juan, 2006). As Figure 1 shows, MCR could analyse the mixed information by separating it into pure component information -- pure concentration profiles and pure spectral signals. It express the variation of a data set through a small bilinear model formed by basic and meaningful contributions (Tauler, 2003).

![Figure 1. The way MCR used to analyse the mixed information of the samples. (Tauler, 2003)](image)

The objective of this study was to analyse the pure components of the multicomponent sample by MCR and study the effect of noise on MCR.

Table 1. The basic samples consisted by PVC and PET with different percentages

<table>
<thead>
<tr>
<th>Name</th>
<th>Hyp1</th>
<th>Hyp2</th>
<th>Hyp3</th>
<th>Hyp4</th>
<th>Hyp5</th>
<th>Hyp6</th>
<th>Hyp7</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>50%</td>
<td>60%</td>
<td>80%</td>
<td>100%</td>
<td>40%</td>
<td>20%</td>
<td>0%</td>
</tr>
<tr>
<td>PET</td>
<td>50%</td>
<td>40%</td>
<td>20%</td>
<td>0%</td>
<td>60%</td>
<td>80%</td>
<td>100%</td>
</tr>
</tbody>
</table>
**Methods**

Matlab R2013a was used to simulate and analyse all data in this study. Matlab stands for MATrix LABoratory and the software is built up around vectors and matrices. This makes the software particularly useful for linear algebra but MATLAB is also a great tool for solving algebraic and differential equations and for numerical integration. Matlab has powerful graphic tools and can produce nice pictures in both 2D and 3D. Matlab also has some tool boxes useful for signal processing, image processing, optimization, etc (Introduction to MATLAB, 2015). In addition, MCR toolbox (Multivariate Curve Resolution Homepage, 2014) was used to analyse the spectra of the samples.

In this experiment, two pure components – Plastic_PETE GDS383 Clrbluis W1R1Fa AREF (PET) and Plastic_PVC GDS338 White W1R1Fa AREF (PVC) (USGS, 2014) were picked to consist the multicomponent sample in Matlab. At first, as the Table 1 shows, seven basic samples were set up by PVC and PET with different percentages and each data had the same structure – 100*100*2151 (x*y*λ, λ is wavelength), and after setting up the data, as the Figure 2 shows, each data was simulated to calculate the meanspectra, which made the structure of data become 1*2151. Then, all meanspectra of the data were simulated to consist the multicomponent sample – X, which was analysed by MCR. During the analysis, Gaussian (Mean is 0 and variance is 0.01) and ‘salt & pepper (the noise density is 0.01) noises were inserted into each face (x*y) of the sample (from λ=1 to λ=2151) to investigate the effect of noise on MCR.

![Figure 2. The processing of simulating the data to calculate its meanspectra in matlab. (Tauler, 2003)](image)

**Results**

*Setting up data in matlab*

The results of setting up data in matlab are as the following figures show:

![Figure 3. The structure of each samples when λ=535](image)
As the Figure 3 show, the black points represents PET and the white space represents PVC.

![Figure 3](image)

Figure 4. The original spectra of materials

According to the Figure 5, the values of reflectance of the samples were decreased when the percentage of PVC that was used in the sample was increased.

**MCR Analysis**

The multicomponent sample – X was analysed by MCR with and without noises additions, and the following figures show the results of the simulation:

![Figure 6](image)

Figure 6. The original spectra of PVC, PET and their sopts before inserting noises into the sample.

Sopt is the pure spectra of each pure component of the sample that is calculated by MCR and according to the Figure 6, the sopt of PVC was almost like the original spectra of PVC, excepting the three points that are marked in the graph as A, B and C. These points mean MCR calculated wrong spectra for PVC. And the sopt of PET totally matched the original spectra of PET, which means MCR calculated right pure spectra of PET.

![Figure 7](image)

Figure 7. The plots of PVC, PET and sopts after inserting Gaussian noise into the sample

![Figure 8](image)

Figure 8. The plots of PVC, PET and sopts after inserting Gaussian and “salt & pepper” noises into the sample
It can be found from Figure 7 and 8 that the sopts of PVC and PET had many more spikes when they were compared with the plots of PVC and PET, but the sopts in Figure 7 were better than that in Figure 8.

Gaussian noise is statistical noise having a probability density function (PDF) equal to that of the normal distribution, which is also known as the Gaussian distribution (Gaussian Noise, 2015). Therefore, the noise was randomly distributed on the sample and some parts of the sample were covered by noise, which meant MCR could only calculate the spectra of the noise in these parts instead of that of pure components. ‘Salt and pepper’ noise also has the characteristic of random distribution. So, when more noise was added to the sample, more original materials were covered by noise, which made the sopt of each pure component have more spikes.

**Conclusion**

Multivariate curve resolution is a soft-modelling method to analyse the pure components of the multicomponent samples. However, noise has an effect on MCR, which makes the sopt of each pure component not match its original spectra and has many more spikes on the sopt of pure components that consist the sample. Therefore, the results of MCR become imprecise. It was also found from the study that the less noise inserted into the sample, the more precise the sopt of each pure component was.

**Future work**

In the next step, real polymer samples will be test by hyperspectral imaging and the data will be analysed by MCR.

**Acknowledgements**

The author is thankful to Chemometrics Group Department of Analytical Chemistry, Universitat de Barcelona.

**Reference**


APPLICATION OF HYPERSPECTRAL IMAGING TECHNIQUE FOR MEASUREMENT OF EXTERNAL DEFECTS OF POTATOES

Wen-Hao Su, Hong-Ju He, Da-Wen Sun
The FRCFT Research Group, School of Biosystems Engineering, University College Dublin, National University of Ireland, Belfield, Dublin 4, Ireland

Abstract

Hyperspectral imaging (HSI) techniques in the wavelength of 400–1000 nm were applied for the rapid and non-destructive measurement of external defects of potatoes. The hyperspectral images of seven potato types were obtained. Then the reflectance spectrums of the interested areas of potato in these hyperspectral images were extracted and analysed. Five feature wavelengths (478, 670, 723, 819 and 973 nm) were selected based on principal component analysis. Principal component analysis was conducted again based on the five selected characteristic wavelengths. Potato external defects were identified through image processing methods, such as threshold segmentation, corrosion, expansion and connectivity analysis. The correct recognition rate of all the seven potato types using principal component analysis method of the characteristic wavelengths achieved 82.50%. The results showed that hyperspectral imaging technique was suitable for rapid and non-destructive assessment of external defects of potatoes.

Introduction

Potatoes are considered as the fourth most important crop in the world after rice, wheat and maize. Furthermore, potatoes as important vegetables, feed and industrial raw materials, are known to have many processing products, e.g., chips (crisps), French fries, dehydrated outputs, and canned sliced tubers, in addition to fresh or table consumed produce. Besides, potatoes with short growth cycle, strong adaptability, high yield, wide range of uses and long industrial chain, have a huge potential of value-added processing. It is known as one of ten popular healthy and nutritious foods, as well as one of the economic crops with best developmental prospect during the 21st century. With such increased expectations, the need for accurate, rapid, and objective quality determination of quality attributes continues to grow. However, some external defects on potatoes seriously affect their qualities. The lack of rapid, reliable and non-destructive methods for determining external defects of potatoes has been one of the main obstacles for the development of quality control in the potato industry. Therefore, the development of rapid and accurate quality inspection techniques with the function of visualizing attribute distribution is important for the potato industry to ensure the quality assurance of potatoes. With the desire for highly correlated automated measurements, it suggests that developing a rapid yet accurate, and possibly non-invasive system can be used as a trusted technique to monitor and help detect the postharvest properties of potato tubers.

Hyperspectral imaging (HSI), which integrates two well-known techniques of spectroscopy and imaging in one system, enables simultaneous acquisition of both spectral and spatial information from an object (Gowen et al 2009). With the advancement of instrument and computing power, HSI has emerged as a novel, rapid and non-destructive tool for quality and safety evaluation in diverse fields including agriculture (Monteiro et al 2007) and food (Gowen et al 2009; Barbin et al 2012; Huang et al 2014; Wold et al 2011).

Recent years, HIS has been emerged and considered as a powerful alternative for the quality measurement of agriculture products. Given the limited information on the usefulness of hyperspectral imaging systems to determine external defects of potatoes, the main aim of this study was to investigate the potential of using HSI techniques as a rapid and non-invasive tool for determining different external defects of potatoes.
Materials and Methods

Samples preparation
The 280 yellow potatoes were collected from several local supermarkets, which included six kinds of defective potato types (e.g. mechanical damage, hole, scab, bruise, sprout, green skin) and one qualified normal potato type. The number of potato samples of each type was 40 in this study.

Hyperspectral imaging system
The system used for acquiring hyperspectral images consisted of Specim V10E spectrograph (Spectral Imaging Ltd., Oulu, Finland) covering the spectral range of 400–1000 nm (spectroscopic resolution of 4.8 nm), a CCD camera (Basler A312f, effective resolution of 1004×668 pixels), objective lens (25mm focal length), illumination source (150W halogen lamp source attached to a fiber optic line light positioned at an angle of 48° to the moving table), mirror, a moving table, acquisition software (SpectralScanner, DV Optics, Padua, Italy) and PC.

Reflectance Calibration and Images Acquisition
Before image acquisition, reflectance calibration was carried out to account for the background spectral response of both the instrument ("W") and the “Dark” camera. The corrected reflectance value (“R”) was calculated from the determined signal (“I”) in a pixel-by-pixel basis as indicated by:

\[ R_i = \frac{I_i - \text{Dark}_i}{W_i - \text{Dark}_i} \]

Where \( i \) is the pixel index, i.e. \( i=1,2,3...,n \) and \( n \) is the total number of pixels within the region of interests (ROI).

The speed of the conveyor was 150 μm/s to ensure that the image size and spatial resolution were not distortion; The exposure time of imaging spectrometer was 10ms to get the best image definition; The actual length of scan line for potato was 160 mm to get all the complete potato images; After device parameters were set up, the 280 hyperspectral images of potatoes were acquired with the system (room temperature 25°C), and data were recorded in units of reflectance and saved in computer.

Data analysis
Average spectra of each kind of potato were extracted from the ROI within its corresponding hyperspectral image using the Region of Interests function of ENVI v4.6 software (Research System Inc., Boulder, Colo., USA). Principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables. The first principal component has the largest possible variance, and each succeeding component in turn has the highest variance possible under the constraint that it is orthogonal to the preceding components. In this study, PCA was used for spectral data dimension reduction, selecting five feature wavelengths (478, 670, 723, 819 and 973 nm) according to the local extremums of weight coefficient curve of the second principal component image of all the potato types. After that, PCA was conducted again based on the five selected characteristic wavelengths, then elected the principal component images where the differences of grey value between the potato defect area and the surrounding area were most obvious. Potato external defects were identified by some image processing methods, such as threshold segmentation, corrosion, expansion and connectivity analysis based on Matlab R2011a(The Math Works Inc., Natick, USA).
Results and Discussion

Based on the first PCA of a full spectral range of 400-1000 nm, the first five principal component images represent almost all the information in the original hyperspectral image data (Fig. 1). The defect area such as surface bruise which was difficult to be identified in the original hyperspectral image, stood out evidently in one of the five principal component (PC) images and could be used to effectively determine the defect potato samples.

![Figure 1. The first five principal component images of potato sample with surface bruise based on the first PCA( I ) and second PCA( II )](image)

Indeed, as the contiguous variables (wavelengths) contain a great degree of dimensionality with redundancy, optimal wavelengths/variables that carry the most useful information should be selected for simplifying the process. Moreover, on the basis of second PCA using the five feature wavelengths, five new PC images of potato sample were produced. By contrast, it was found that the new PC images were extremely similar to the former five PC images (Fig. 1). It means that an optimized multispectral imaging system could be developed, which would have a lower price and higher speed than a hyperspectral imaging system.

![Figure 2. PC images( I ) and threshold segmentation results( II ) of potato samples with different types of surface conditions based on the second PCA](image)

Defective areas of mechanical damage potato samples stood out in PC5 images. Defective areas of scab and green skin potato samples emerged in PC2 images. Defective areas of potatoes with holes, surface bruise and sprout came out clearly in PC3 images. Compared with other PC images, these PC images were more convenient for image recognition analysis (Fig. 2). Potato external defects were identified after some image processing methods, such as threshold segmentation, corrosion, expansion and connectivity analysis (Fig. 2).
Table 1. Results for developed algorithms based on 280 potatoes with different defect types

<table>
<thead>
<tr>
<th>Type</th>
<th>Sample numbers</th>
<th>Non-identification numbers</th>
<th>Correct recognition rate/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical damage</td>
<td>40</td>
<td>9</td>
<td>77.5</td>
</tr>
<tr>
<td>Hole</td>
<td>40</td>
<td>5</td>
<td>87.5</td>
</tr>
<tr>
<td>Scab</td>
<td>40</td>
<td>7</td>
<td>82.5</td>
</tr>
<tr>
<td>Surface bruise</td>
<td>40</td>
<td>8</td>
<td>80</td>
</tr>
<tr>
<td>Sprout</td>
<td>40</td>
<td>11</td>
<td>72.5</td>
</tr>
<tr>
<td>Green skin</td>
<td>40</td>
<td>5</td>
<td>87.5</td>
</tr>
<tr>
<td>Normal</td>
<td>40</td>
<td>4</td>
<td>90</td>
</tr>
<tr>
<td>Total</td>
<td>280</td>
<td>49</td>
<td>82.5</td>
</tr>
</tbody>
</table>

Based on this algorithm, the better correct recognition rates for potatoes with hole, scab, surface bruise, and green skin, as well as qualified normal potatoes were 87.50%, 82.50%, 80.00%, 87.50% and 90.00%, respectively (Table 1).

Conclusions

A hyperspectral imaging system in the visible and NIR region of 400-1000 nm was developed to determine external defects of potatoes. Out of 125 wavelengths, only five wavelengths were selected by analyzing loading weights. The recognition rate of all the seven potato types using the principal component analysis method to characteristic wavelengths was 82.50%. The overall results showed the potential of applying hyperspectral imaging techniques for rapidly and non-destructively predicting external defects of potatoes.

Acknowledgements

The authors would like to acknowledge the financial supports from University College Dublin (UCD) and the China Scholarship Council (CSC).

References


APPLICATION OF NEAR-INFRARED HYPERSONTICAL IMAGING FOR NON-DESTRUCTIVE DETERMINATION OF 2-THIOBARTURIC ACID (TBA) VALUE IN ATLANTIC SALMON (Salmo salar) FILLETS

Jun-Li Xu, Cecilia Riccioli and Da-Wen Sun
The FRCFT Research Group, School of Biosystems Engineering, University College Dublin, National University of Ireland, Agriculture & Food Science Centre, Belfield, Dublin 4, Dublin, Ireland

Abstract
This study investigated the potential of using hyperspectral imaging technique in the near infrared region (900–1700 nm) for rapid and non-invasive determination of 2-thiobarbituric acid (TBA) value for monitoring lipid oxidation in Atlantic salmon (Salmo salar) fillets during cold storage. Hyperspectral cubes were acquired at different storage stages and their corresponding spectra data were extracted. Partial least square regression (PLSR) calibration models were established with full spectral region between the spectral data and the reference TBA values. Good performance for predicting TBA value was observed with determination coefficients ($r_p$) of 0.85 and root-mean-square errors of prediction (RMSEP) of 2.24 µmol MDA/kg fish. The research demonstrated that hyperspectral imaging technique is suitable for rapid and non-destructive evaluation of lipid oxidation in salmon flesh during cold storage.

Introduction
Due to the high content of polyunsaturated fatty acids, fish is highly susceptible to undergoing lipid oxidation which is regarded as one of the most significant mechanisms leading to food spoilage. As a result, fat-rich fish such as salmon, mackerel and herring are prone to high risks of shelf life reduction and nutritional quality loss due to changes in taste and/or flavour, deterioration of the texture and development of some toxic substances. Lipid oxidation in fish generally involves a complex chain of reactions, with hydroperoxide produced as the major product of primary oxidation. Hydroperoxides are further decomposed into a complex mixture of secondary oxidation products including aldehydes, epoxides, hydroxyl compounds, oligomers, polymers and ketones (Franke 1984), all of which mainly account for undesirable sensory and biological effects and give rise to toxic compounds related with rancidity. Traditional methods to assess the rate and extent of lipid oxidation are time-consuming, laborious and destructive. Therefore, advanced and non-invasive techniques are urgently needed both in research and industry.

In recent years, hyperspectral imaging technique (HSI) has established itself as one of the most versatile tools in food analysis. Combined spectroscopy and computer vision into one system, HSI is able to obtain a spatial map of spectral variation of the objective sample (Sun 2010). The goal of this study was to investigate the application of near infrared HSI technique to determine the 2-thiobarbituric acid (TBA) value for monitoring lipid oxidation in Atlantic salmon (Salmo salar) fillets during cold storage at 0°C for 0, 3, 6, 9 and 12 days.

Materials and Methods
Fish sample preparation
A total of 150 fresh Atlantic salmon (Salmo salar) fillets originated from Norway were labelled and then transported to laboratory of UCD. All the samples were packed and stored
in -18 °C for three months. After frozen storage, fillets were thawed and randomly divided into five groups subjected to cold storage for 0, 3, 6, 9 and 12 days at 1±1 °C in a refrigerator. Samples were first scanned by HSI system and then immediately measured TBA values.

**Hyperspectral image acquisition and calibration**

The HSI system used is similar to the system II used by Wu and Sun (2013). Each salmon fillet was firstly taken from the refrigerator, placed on the translation stage and then conveyed to the field of view (FOV) of the camera to be scanned line by line. Afterwards, two additional standard images, namely the white Teflon tile (ca. 99% reflectance) and the dark current (ca. 0% reflectance) were also acquired in order to correct the raw images (R₀) from the dark current of camera. The calibrated image (Rₛ) of sample was calculated using the following formula with the aid of the two standard images obtained as aforementioned:

\[ Rₛ = \frac{(R₀ - Rₚ)}{(Rₘ - Rₚ)} \]

where \( Rₚ \) is the dark current image of camera recorded with the light source all off and the camera lens completely covered with its opaque cap and \( Rₘ \) is the white reference image achieved from a white Teflon tile as reference.

**TBA value measurement**

Thiobarbituric acid reactive substances (TBA-RS) was determined according to the procedure described by Salih et al. (1987) with some modifications. Approximately 2 gram of Salmon fillet flesh was firstly minced with 15 ml 5% cold perchloric acid and then homogenized by shaking for one minute, followed by centrifuging for 10 minutes at 3000g and filtrated. Filtrate (10 mL) was mixed with 10 mL of 20 mmol/L 2-thiobarbituric acid (TBA) and subsequently incubated in boiling water for 40 minutes. After cooled for 10 min with running tap water, the absorbance was determined at 532 nm by a spectrophotometer, with the mixture of 10 mL of 5% perchloric acid and 10 mL of TBA solution as the blank. The TBA value was expressed as micromoles malondialdehyde (MDA)/kg fish meat.

**Multi-variable data analysis**

In this study, Matlab 7.7 R2008b software (The Mathworks Inc., USA) was applied to extract the spectral from the region of interest (ROI) and the spectra of all pixels within ROIs were then averaged to represent the mean spectral data of each tested fish fillet. As a popular multivariate data analysis, partial least square regression (PLSR) was conducted to establish quantitative models to relate the spectral data with the reference TBA values.

**Results and Discussions**

**Spectral feature analysis**

The averaged spectra data extracted from the pixels within the ROIs in the 967–1565 nm spectral range during different cold storage days are shown in Fig. 1. Obviously, samples stored in different days shared the similar spectral patterns throughout the whole wavelengths region. However, major differences in the magnitudes of spectral reflectance value can also be illustrated. The fresh samples with low TBA values (Day 0 and day 3) had demonstrated the lowest reflectance, while higher reflectance was found in the samples stored more than 9 days with the maximum lipid oxidation. Meanwhile, the variations of the spectra can be well explained by the overtone and combination vibrations of the molecular chemical bonds, such as O–H, C–H and N–H. The presence of water in the flesh contributed to two feature
wavelengths at 980 nm and 1450 nm (O-H stretching second and first overtones) in Fig.1 (Wu and Sun 2013). Besides, the absorption peak located near 1200 nm relating to C-H stretching second overtone was possibly due to fat content.

![Figure 1: Mean spectral features of the salmon samples during storage.](image)

**Quantitative modelling based on full range spectra**

Specifically, the PLSR calibration model was developed based on the reflectance spectra of 150 samples at all 180 wavelengths as X-variables and the reference measured TBA values as Y-variable. To enhance the ability of prediction model, extended scatter correction (EMSC) was applied as a pre-processing technique to eliminate the undesirable scattering effect from the data matrix. In this study, Kennard-Stone algorithm (Saptoro et al. 2012) was used to automatically split all samples into calibration and validation subsets. To be more precise, two thirds samples (n = 100) were used to create the calibration models and the remaining one third samples (n = 50) were used as validation subset. Besides, venetian blinds cross-validation was also applied for cross validation purpose. To build a robust model, a reasonable range of TBA value variation should be guaranteed both for the calibration and validation subsets covering both the healthy samples and spoilage samples. Generally speaking, samples with TBA value lower than 8 µmol MDA/kg fish are of superior quality while with value higher than 20 indicate unacceptable spoilage. Table.1 summarizes the descriptive statistics of TVB values for both the calibration set and validation set.

Technically, 11 latent variables (LVs) of the PLSR model was determined and obtained by the lowest value of predicted residual sum of squares (PRESS). Good result was achieved in both calibration and prediction condition with r² of 0.932 and r² of 0.846, root-mean-square errors of calibration (RMSEC) of 1.77 µmol MDA/kg fish and root-mean-square errors of prediction (RMSEP) of 2.24 µmol MDA/kg fish. Fig. 2 shows the efficiency and robustness of the PLSR model. The achieved model confirms the suitability of using hyperspectral imaging technique to predict TBA values in a non-destructive and rapid way.

<table>
<thead>
<tr>
<th>Table 1. Data statistic for reference TBA values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
</tr>
<tr>
<td>Calibration set</td>
</tr>
<tr>
<td>Prediction set</td>
</tr>
</tbody>
</table>
Conclusions
The PLSR calibration model developed based on full wavelengths generated good and satisfactory prediction results for TBA values with $r_c$ and $r_p$ of 0.932 and 0.846, and RMSEC and RMSEP of 1.77 and 2.24 µmol MDA/kg fish respectively. This study confirms the suitability of using hyperspectral imaging technique to non-invasively analyse TBA value in salmon fillets.

Acknowledgements
The authors would like to acknowledge China Scholarship Council (CSC) and University College Dublin (UCD) for financial support of this study under CSC-UCD Scheme.

Reference


MOISTURE CONTENT DISTRIBUTION IN MANGO SLICES DURING MICROWAVE-VACUUM DRYING USING NIR HYPERSPECTRAL IMAGING

Yuan-Yuan Pu, Da-Wen Sun*
Food Refrigeration and Computerized Food Technology (FRCFT), School of Biosystems Engineering, Agriculture & Food Science Centre, University College Dublin, Belfield, Dublin 4, Ireland

Abstract
Dried mango slices were obtained by using a microwave-vacuum drying system. Moisture content of the mango slices during the drying process was analyzed. Spectral and spatial information of each mango slice was acquired by a lab-scale NIR hyperspectral imaging system. The Page model, with a higher fitting precision of $R^2 = 0.978$, was found to describe the current drying process. For moisture content prediction, partial least square (PLS) was applied to correlate the mean spectrum and the referenced moisture content of each mango slice. Feature wavebands were extracted for moisture content prediction by stepwise regression (SR) and competitive adaptive reweighted sampling (CARS). Prediction performance of PLS models based on full-wavelength range (FW) and the selected important wavebands were compared. The coefficients of determination ($R^2$) and the root mean square errors for prediction (RMSEP) of FW-PLS model, SR-PLS model and CARS-PLS model were 0.969, 0.962, 0.971 and 4.796%, 5.340%, 4.891%, respectively. The simplified model CARS-PLS was implemented into the moisture visualization procedure. The present study demonstrated that hyperspectral imaging was a useful tool for non-destructively and rapidly measuring and visualizing the moisture content during drying process.

Introduction
Dried mango is very popular in the world market due to its high nutrition and long shelf-life. Microwave-vacuum drying (MVD) is a novel drying method which integrates the advantages of microwave heating and vacuum drying. However, the non-uniform heating property of MVD might lead to uneven dried products (Vadivambal and Jayas 2010). Thus, quality supervision of the end products or products being processed during drying is required.

Moisture content (MC) is one of the most important quality parameters for dried food products. Traditionally, oven-drying, Karl-Fischer titration, and distillation were carried out for the measurement of moisture content. Recently, NIR spectroscopy were utilized for moisture content determination since the O-H functional group in water absorbs energy at certain wavebands during electromagnetic radiation. The main disadvantage of the current spectroscopy lies in its point or partial detecting nature, which could not provide the whole sample information in one measurement.

Hyperspectral imaging (HSI) is a combination of the computer vision technique and spectroscopic technique, which has been applied extensively for safety and quality assessment of various fruits. Prediction of moisture content (MC) in strawberries, bananas, and mushrooms using HSI has been investigated. However, research on the drying kinetics of mango slices during MVD and the influence of microwave heating on moisture distribution were limited in the above studies. The aim of the study was to understand the drying kinetics of mango by fitting the experimental data to four thin-layer drying models, and to visualize moisture content distribution in mango slices during MVD using emerging HSI.
Materials and Methods

Sample preparation
The Mangoes (Tommy Atkins, Brazil) used in the study were purchased from a local market. A stainless steel slicer was used to slice the mango flesh into 5 mm. Test samples (3×3 cm in size) were cut from the flesh slices by a knife.

Drying system
The microwave vacuum drying system was mainly equipped with a domestic microwave oven (Panasonic NN-CF778S, Panasonic Manufacturing U.K.Ltd, Cardiff, UK) and a vacuum pump (Edwards RV3, Edwards limited, West Sussex, UK). The microwave power was set at 250 W and pressure was maintained at 20±2 mbar. The drying process was conducted intermittently, with one minute heating-on followed by two minutes heating-off. Mango slices with a certain heating time of 0, 3, 6, 9, 12, 15, 20, 25, and 30 min were taken out for image acquisition.

Image acquisition and calibration
NIR hyperspectral imaging system performing in a spectral range of 880-1720 nm with a spectral resolution of 7 nm was employed for image acquisition. The major components of the system were described elsewhere (Gowen et al. 2008). The raw images were calibrated automatically by the system using a dark and a white reference image.

Moisture content measurement
Moisture content of the mango slices at different drying stages were measured by thermo-gravimetric method using a convective hot-air oven (Gallenkamp Plus II, UK) at 105°C for 24 h. Samples before and after oven-drying were weighed. The moisture content was calculated on a wet basis (w.b.) and expressed as follows:

\[
\text{Moisture Content (\%, w.b.)} = \left(1 - \frac{W_a}{W_b} \right) \times 100
\]

where \(W_b\) and \(W_a\) were sample weight before and after oven drying.

Data analysis and visualization
The spectral signals of all pixels in each mango slice were averaged to obtain a mean relative reflectance spectrum, which was used for subsequent analysis. In order to simplify the modelling process, two wavelength selection strategies, namely stepwise regression (SR), and competitive adaptive reweighted sampling (CARS), were used. The mean spectra and the reference moisture contents were correlated by partial least squares (PLS) regression. Prediction performance of PLS models developed based on full-wavebands, wavebands selected by SR or CARS were compared using the coefficients of determination (\(R^2\)) and the root mean square errors (RMSE).

Results and Discussion

Drying kinetics
In order to investigate the drying kinetics of mango slices during current MVD process, four thin-layer drying models describing the relationship between moisture ratio (\(MR = MC/MC_i\), where \(MC_i\) and \(MC\) represent the initial moisture content and the moisture content of mango slices at a certain heating time \(t\), respectively) and microwave-heating time \(t\) were selected. Table 1 shows the results of the model constants and coefficients (\(a, b, c, k, k_1, k_2,\) and \(n\)), and the fitting precision (\(R^2\) and RMSE). It showed that all models had an acceptable \(R^2\) (>0.88) and RMSE (<0.12). Among the four models, the Page model had the highest value of \(R^2\) and the lowest value.
of RMSE, which was 0.978 and 0.052, respectively. Therefore, the Page model was considered as the optimal models to describe the mango drying kinetics during MVD.

Table 1. Moisture ratio (MR) as a function of microwave-heating time (t).

<table>
<thead>
<tr>
<th>Model</th>
<th>Model equation</th>
<th>Reference</th>
<th>Parameter</th>
<th>$R^2$</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newton</td>
<td>$MR=\exp(-kt)$</td>
<td>(Nellist 1987)</td>
<td>k=0.05128</td>
<td>0.893</td>
<td>0.114</td>
</tr>
<tr>
<td>Page</td>
<td>$MR=\exp(-kt^n)$</td>
<td>(Abe and Afzal 1997)</td>
<td>k=0.005714; n=1.8</td>
<td>0.978</td>
<td>0.052</td>
</tr>
<tr>
<td>Henderson and Pabis</td>
<td>$MR=ae^{(-kt)}$</td>
<td>(Thakur and Gupta 2006)</td>
<td>a=1.128; k=0.05973</td>
<td>0.913</td>
<td>0.103</td>
</tr>
<tr>
<td>Logarithmic</td>
<td>$MR=ae^{(-kt)}+c$</td>
<td>(Yaldiz et al. 2001)</td>
<td>a=2.111; k=0.02167; e=−1.033</td>
<td>0.941</td>
<td>0.085</td>
</tr>
</tbody>
</table>

Comparison of PLS models

The important wavebands for moisture content prediction were extracted by SR or CARS. PLS models on full-wavelength range and the selected wavelengths were developed and compared. As shown in Table 2, the FW-PLS model using 121 wavebands gave a good prediction performance, with $R_p^2=0.969$ and RMSEP=4.796%. However, by using two feature wavebands selected by SR (1398 and 1573 nm) or CARS (1342 and 1405 nm), an equivalent or even better prediction performance compared to FW-PLS model were achieved, with $R_p^2$ of 0.962, 0.971 and RMSEP of 5.340%, 4.891%, respectively.

Table 2. Model performance comparison.

<table>
<thead>
<tr>
<th>Model</th>
<th>Wavebands (nm)</th>
<th>No. of Wavebands</th>
<th>Calibration</th>
<th>Cross-validation</th>
<th>Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R_c^2$</td>
<td>RMSE (%)</td>
<td>$R_{cv}^2$</td>
<td>RMSE (%)</td>
<td>$R_p^2$</td>
</tr>
<tr>
<td>FW-PLS</td>
<td>880-1720</td>
<td>121</td>
<td>0.985</td>
<td>3.539</td>
<td>0.981</td>
</tr>
<tr>
<td>SW-PLS</td>
<td>1398, 1573</td>
<td>2</td>
<td>0.962</td>
<td>5.596</td>
<td>0.961</td>
</tr>
<tr>
<td>CARS-PLS</td>
<td>1342, 1405</td>
<td>2</td>
<td>0.971</td>
<td>4.920</td>
<td>0.970</td>
</tr>
</tbody>
</table>

Moisture content distribution

The best simplified model CARS-PLS was employed to generate the moisture content prediction map. According to the moisture content value, each pixel in the mango image was assigned to a specific color from the linear color scale. The moisture distribution map is shown in Figure 1. The raw mango slice as shown in Figure 1 (a) displayed a more uniform red color, showing that its moisture content was relatively high. Moisture content of eight mango samples with different drying time were shown in Figure 1 (b). Interestingly, uneven color distribution on those mango slices was observed, suggesting that the moisture content was uneven in the same sample. It was found that at the four corners the moisture content was relatively high, while lower in the central part. This could be associated with the non-uniform temperature distribution on food materials during microwave heating, since temperature distribution is affected by several factors, for example, the microwave power distribution, the dielectric properties of food materials, and the size or shape of the samples (Vadivambal and Jayas 2010, Chandrasekaran et al. 2013). Under the current experiment conditions, the absorbed heat energy in the central part of mango slices might be more difficult to dissipate, leading to a higher temperature in the center and thus the water evaporation rate was higher, resulting in a drop in moisture content.
Figure 1. Moisture distribution of mango slices during microwave-vacuum drying. (a) raw mango slice; (b) mango sliced dried by MVD.

Conclusions
The Page model was suitable to describe the current drying process, with a fitting goodness of 0.978. NIR hyperspectral imaging is promising in predicting and visualizing moisture content variation of mango slices during MVD. PLS model based on two wavebands (1342 nm and 1405 nm) selected by CARS showed the best prediction behaviour, with $R_p^2$ of 0.971 and RMSEP of 4.891%.

Acknowledgements
The authors would like to acknowledge the University College Dublin (UCD) and China Scholarship Council (CSC) for the support of this research.

References
VISUALIZATION OF PSEUDOMONAS LOADS OF SALMON FLESH USING NEAR-INFRARED HYPERSONTAL IMAGING TECHNIQUE

Hong-Ju He, Da-Wen Sun
FRCFT Research Group, School of Biosystems Engineering, Agriculture & Food Science Centre, University College Dublin, Belfield, Dublin 4, Ireland

Abstract

The feasibility of near-infrared hyperspectral imaging in the range of 900−1700 nm (NIR) for predicting Pseudomonas loads on salmon flesh were investigated. Hyperspectral images of salmon samples stored at different days were acquired and spectral information was extracted to relate to reference values of Pseudomonas loads measured by traditional Pseudomonas CFC-selective medium, using partial least square (PLS) regression algorithm. The quantitative relationship between the spectra and the measured Pseudomonas loads was established, leading to a PLS model with correlation coefficient of prediction (Rp) of 0.95 and root mean square error of prediction (RMSEP) of 0.52. Competitive adaptive reweighted sampling (CARS) algorithm was applied to select the most important wavelengths (941, 1105, 1161, 1178, 1222, 1242, 1359, 1366, 1628 and 1652 nm) to simplify the PLS model. With the ten important wavelengths, a CAR-PLS model was developed with Rp of 0.95 and RMSEP of 0.49. By transferring the CARS-PLS model to each pixel of hyperspectral images of samples, Pseudomonas load distribution was mapped to display the spatial variation of Pseudomonas load from sample to sample and spot to spot within the same sample. The overall results indicated that NIR hyperspectral imaging technique has a great potential and could be used for determining Pseudomonas loads on salmon flesh during the cold storage.

Introduction

Pseudomonas is one kind of spoilage microorganisms and is easy to grow and reproduce in salmon flesh, as it is characterised by easy-to-survive with simple nutrition (Feng & Sun, 2013). Pseudomonas load is often used as an important indicator for quality and shelf-life assessment of salmon fillets (Briones et al., 2010; Hozbor et al., 2006). Routine techniques for detection of Pseudomonas loads mainly includes standard pour plate method (Álvarez et al., 2012), molecular-based method (Doulgeraki & Nychas, 2012) and immunology-based method (Kitaguchi et al., 2005). Although these methods are very useful and effective, they are always laborious, time-consuming, destructive and thus not suitable for fast and real-time inspection. Moreover, they cannot meet the requirements in the situation where a large number of samples are needed to be evaluated in terms of microbial contamination, like PC values. Therefore, it is necessary to develop an advanced technique to determine Pseudomonas loads in a rapid, non-destructive and efficient way, satisfying the increasing demands of producers and consumers.

In recent years, a promising technique called hyperspectral imaging has been emerged by integrating spectroscopic and computer vision techniques into one system (Sun, 2010). Hyperspectral imaging used for food analysis lies in its ability of providing not only spectral information related to quality attributes but also spatial information used for visualisation of the distribution of these attributes (He et al., 2013). Endeavours on use of hyperspectral imaging for quality evaluation have been reported in various kinds of food products (Barbin et al., 2013; Yoon et al., 2011). Recently, salmon flesh has been evaluated and assessed in terms of physical and chemical attributes (Wu & Sun, 2012ab; He et al., 2014ab). In this study, the aim was to investigate the potential of NIR hyperspectral imaging for rapid determination of Pseudomonas loads in farmed salmon flesh during cold storage. In addition, the spatial distribution of Pseudomonas loads at different storage times was also visualized.
Materials and Methods

Sample preparation
Thirty fresh farmed salmon fillets originated from Norway were provided by local supermarkets in Dublin, Ireland. The fillets were vacuum-packed and transported to the laboratory of FRCFT, UCD, Ireland. Sampling was then performed by cutting each fillet into 3 cm × 3 cm × 1 cm (length × width × thickness, about 10 g). The 93 samples were then re-packed using cling film, labelled and stored at 4 °C.

Image acquisition
A lab hyperspectral imaging system was used for image acquisition and the details can be found in the study of He et al. (2013b). Because of the low signal-to-noise ratio in the two ranges of 897–900 nm and 1700–1753 nm, only the wavelength range of 900–1700 nm was used for further data analysis.

Image processing
Image calibration was performed by using the following formula:

\[ I_c = \frac{I_R - I_B}{I_W - I_B} \times 100 \]  

where \( I_c \) is the calibrated hyperspectral image in a unit of relative reflectance (%); \( I_R \) is the raw acquired hyperspectral image; \( I_W \) is the reference white image collected by scanning and recording an image of a white ceramic tile with about 99.9% reflectance; \( I_B \) is the reference black image (~ 0% reflectance) achieved by turning off the light source and covering the camera lens completely.

Microbial measurement
According to Sallam (2007), the Pseudomonas load was measured by Pseudomonas CFC-selective medium (CM 559 + SR 103, Oxoid, Basingstoke, UK) and recorded as colony-forming units (log 10 CFU/g).

Data extraction and analysis
The spatial ROIs of hyperspectral images of samples were identified by software ENVI v4.6. Spectral information of each pixel within the ROI were extracted and then averaged into one single spectrum representing the ROI, which was performed using the software Matlab R2010b. PLS was applied to establish the quantitative relationship between the extracted spectra and the reference Pseudomonas load values.

Wavelength selection and model optimization
CARS was applied to select the most important wavelengths and the PLS model was optimized with the selected important wavelengths.

Visualization
The optimized model was transferred and the distribution map was generated.

Results and discussion
Modeling with full wavelength
Based on the full wavelength range of 900-1700 nm, a PLS model was developed and the performance is shown in Table 1. The PLS model exhibited a good ability in predicting Pseudomonas load of salmon flesh.
Table 1. Results of model calibration by using full wavelengths and selected most important wavelengths, respectively

<table>
<thead>
<tr>
<th>Model</th>
<th>Number of wavelength</th>
<th>Number of latent factors</th>
<th>Calibration set</th>
<th>Prediction set</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$R_C$</td>
<td>RMSEC</td>
</tr>
<tr>
<td>PLSR</td>
<td>239</td>
<td>8</td>
<td>0.96</td>
<td>0.45</td>
</tr>
<tr>
<td>RC-PLSR</td>
<td>10</td>
<td>5</td>
<td>0.97</td>
<td>0.40</td>
</tr>
</tbody>
</table>

**Modeling with the important wavelengths**

Using the CARS, ten individual wavelengths at 941, 1105, 1161, 1178, 1222, 1242, 1359, 1366, 1628 and 1652 nm were selected as the most important wavelengths. With the ten important wavelengths, an optimised model named CARS-PLS was built and the performance of the CARS-PLS model is shown in Table 1. Although the wavelength number reduced from 239 to 10, the performance of the CARS-PLS model was similar to the original PLS model developed with full wavelength. Moreover, the $|RMSEC - RMSEP|$ value of CARS-PLS model was 0.09, almost the same as that in PLS model, which indicated that the CARS-PLS model had the similar robustness compared with PLS model. Besides, the RPD value of 3.32 in CARS-PLS model was close to that (3.12) of PLS model, which showed the similar abilities of the two models in predicting Pseudomonas load of salmon samples. In general, the use of CARS for important wavelength selection was helpful to optimize the PLS model and keep the similar prediction accuracy and robustness.

**Distribution of Pseudomonas load**

To visualise the Pseudomonas load variation from sample to sample and even from spot to spot within a sample, the CARS-PLS model was transferred to each pixel of hyperspectral images. With such maps, understanding of Pseudomonas load spoilage process could be enhanced and that make hyperspectral imaging more useful and advantageous in microbial evaluation of salmon fillets, than the traditional NIR spectroscopy. As shown in Fig. 1, examples of distribution maps were exhibited to observe how much spoilage degree of salmon flesh changed during the cold storage. The spoilage degree was illustrated using a linear colour scale, in which blue colour was assigned to indicate the low spoilage degree while the red colour was used to represent the high degree. With the extension of storage time, salmon samples were spoiled gradually from light to heavy.

![Figure 1. Distribution maps for visualising Pseudomonas load of samples at different storage times.](image)

**Conclusions**

Quantitative CARS-PLS modeling coupled with a Pseudomonas load visualisation map made NIR hyperspectral imaging for Pseudomonas load evaluation of salmon flesh more objective, reliably and comprehensive. The spectral information was mined and spatial Pseudomonas load variation was imaged to provide a potential way for monitoring the microbial spoilage process when salmon flesh is stored in cold conditions. The results indicated that hyperspectral imaging could be used as a useful and promising technique to assess the Pseudomonas spoilage of salmon flesh.
Acknowledgements

The authors would like to acknowledge the financial support provided by the Irish Research Council for Science, Engineering and Technology under the Government of Ireland Postdoctoral Fellowship scheme.

References


MIGRATION ASSESSMENT OF NANOPARTICULATE SILVER, COPPER AND GALLIUM FROM AN EXPERIMENTAL NANOPARTICLE/PS-B-PEO COATED FOOD PACKAGING

Joseph C. Hannon\textsuperscript{a}, Joseph Kerry\textsuperscript{b}, Michael Morris\textsuperscript{c}, Malco Cruz-Romero\textsuperscript{b} and Enda Cummins\textsuperscript{a}

\textsuperscript{a} UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.
\textsuperscript{b} School of Food & Nutritional Sciences, Food Packaging Group, University College Cork, Cork, Ireland.
\textsuperscript{c} Department of Chemistry, University College Cork, Cork, Ireland.

Abstract

Assessment of the migration of nanoparticles (NPs) from novel food packaging into food destined for human consumption is crucial to ensure regulatory compliance and acceptance of such materials by regulatory bodies. To assess the level of NP migration from a novel NP/polystyrene - polyethylene oxide block copolymer (PS-b-PEO) coating, two complimentary techniques were used; inductively coupled – atomic emission spectroscopy (ICP-AES) and scanning electron microscopy (SEM). The presence of silver (Ag), copper (Cu) and gallium (Ga) NPs in each of the three coatings was confirmed by SEM prior to migration studies. The migration levels observed in 3% acetic acid (3% HAc) after incubation for 10 days at 60 \( ^\circ \)C using ICP-AES were 0.781 mg \( l^{-1} \), 1.374 mg \( l^{-1} \) and 1.332 mg \( l^{-1} \) for AgNP, CuNP and GaNP samples, respectively. Although the NP migration detected for each of the nanocoatings far exceeds the regulatory limits (European Commission Reg. No. 10/2011) the significantly lower migration observed for the AgNP coating suggests that AgNPs are potentially the best candidate for further development as an active additive in food packaging materials and require further investigation.

Introduction

The advent of packaging materials containing particles in the size range 1 – 100 nm and possessing antimicrobial properties has resulted in the potential to improve food safety at every stage from supplier to consumer. In particular, metal nanoparticles such as AgNPs, CuNPs and GaNPs which possess strong antimicrobial properties could be immobilised at the surface of packaging to release ionic species directly into food to achieve their active function. In spite of the benefits associated with their antimicrobial activity, there are concerns in relation to the migration of NPs into food and their potential human toxicity once consumed. Although NP toxicity is strongly linked with their ability to release ionic species, NP size allows them to penetrate natural barriers and accumulate in vital organs (Hannon et al. 2015). As a result, it is of the utmost importance that the human risk from exposure to nanoparticles is assessed before such products are placed on the market. This is particularly important for NP packaging surface coatings due to the limited number of studies in the literature focussing on this area (Hannon et al. 2015).

Currently there is no recognised \textit{gold standard} technique to assess the migration level of NPs from food packaging into food (Cushen et al. 2014). Consequently, it is necessary to use a set of techniques such as ICP-AES and SEM to quantify and characterise NPs in food matrices and food simulants. Following a migration assessment using these techniques, a decision in relation to the use of a material as food packaging can be made based on the level of migration. Subsequent decisions can be classified into three categories based on the observed migration; 1) no migration: therefore no human risk, 2) migration below conventional limits: proceed to nano-specific toxicity assessment, and 3) migration above conventional limits: material rejected for use as a food packaging material.

The objective of this study was to characterise and quantify the level of migration of three types of metal nanoparticles coated on a model food packaging material using ICP-AES and SEM techniques.
Materials and Methods

Nanocomposite manufacture
The metal NP/polymer coating was manufactured using the method presented by Azlin-Hasim et al. (2015). Ultrasonically cleaned glass slides (size 2.5 cm × 2.5 cm) were spin coated with PS-b-PEO (1 wt.% in toluene) at 3000 rpm for 30 s using a modified procedure according to Ghoshal et al. (2012). Following the microphase separation of BCP in the film using a solvent-annealing technique, the coated slides were dried using a N₂ gas stream. The subject metals were spin coated to the PS-b-PEO surface as metal precursors (i.e. AgNO₃ is the precursor for Ag) and then exposed to UV Ozone for 3 hours to remove organic polymer residues and any residual solvent. In addition, the UV Ozone treatment oxidised the metal ions present in the precursor into metal nanodots.

To confirm the presence of NPs in each of the nanocomposites, samples were placed coated side up on carbon tape, gold coated (Agar sputter coater with gold target, Agar Scientific, Essex, UK) and imaged by scanning electron microscopy (Hitachi S-4300 field emission SEM, Hitachi High Technologies America, Inc., USA). SEM images were analysed in the freeware programme Fiji (Schindelin et al. 2012).

Migration characterisation
Migration studies were carried out according to European Commission Regulation No. 10/2011 (European Commission (EU) 2011) to determine the amount of NPs that are released from the nanocomposite. Nanocomposite samples were immersed in 3% HAc food simulant and incubated in an oven (Plus II Oven, Gallenkamp, Loughborough, UK) for 10 days at 60 °C to simulate worst case conditions of migration for storage times greater than 6 months. Once the 10 day incubation period had elapsed samples were removed from there sample pots and a 5 ml aliquot of each 6.25 ml food simulant sample was isolated for the ICP-AES analysis. A pre-digestion step was carried out on each aliquot to ensure all metals were in ionic state before ICP-AES analysis. The 5 ml aliquot was placed in a pyrex tube along with 0.1 ml of 69% HNO₃ (VWR International, Dublin, Ireland) and 0.05 ml of 37% HCL (Sigma-Aldrich, Arklow, Ireland). The pyrex tubes were sealed tightly and heated at 95 ± 5 °C for 2.5 hours using a test tube heater (Palintest Digital Tubetests Heater, Gateshead, UK).

The quantity of NPs which migrated during incubation was then determined using an ICP-AES (Vista Pro RL, CCD simultaneous ICP-AES, Varian, Victoria, Australia). The ICP-AES was calibrated using four standards ranging from 0.01 – 5 mg l⁻¹ which were prepared by serial dilution of a stock standard solution (1000 mg l⁻¹ Ag⁺ in HNO₃, 1000 mg l⁻¹ Ga⁺ in HNO₃ and 5 mg l⁻¹ Cu in multi-element standard, Elementec, Kildare, Ireland). To highlight any spectral interferences due to matrix effects yttrium was included in all standards and samples at a concentration of 1 mg l⁻¹ (1000 mg l⁻¹ Y in HNO₃, Elementec, Co. Kildare, Ireland). To remove any potential sources of contamination in the study, all of the apparatus which contacted the food simulant was soaked in a 5% HNO₃ bath for 24 hours and then rinsed with drop-wise HNO₃ and distilled water.

Results and Discussion

Migration
As seen in Table 1 the migration of AgNPs, CuNPs and GaNPs from the nanocoating into 3% HAc far exceeds the migration limit of 0.01 mg kg⁻¹ for unauthorized substances established in European Commission Regulation No. 10/2011. Despite this finding, significantly less migration was observed for the AgNP samples. This suggests a superior bonding potential between the AgNPs and the packaging substrate when compared to CuNPs and GaNPs. In a study carried out by Azlin-Hasim et al. (2015) the antimicrobial efficacy of the AgNP coated glass slides was demonstrated against both gram positive and gram negative bacteria. The authors noted that the antimicrobial activity exhibited
could be obtained at a lower AgNP concentration than used in the study, presenting a basis for a reduction in migration.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Replicate 1 [mg l^{-1}]</th>
<th>Replicate 2 [mg l^{-1}]</th>
<th>Replicate 3 [mg l^{-1}]</th>
<th>Mean Migration [mg l^{-1}]</th>
<th>Standard Deviation [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6% Ag</td>
<td>0.408</td>
<td>0.909</td>
<td>1.027</td>
<td>0.781</td>
<td>0.329</td>
</tr>
<tr>
<td>0.6% Cu</td>
<td>1.297</td>
<td>1.540</td>
<td>1.284</td>
<td>1.374</td>
<td>0.144</td>
</tr>
<tr>
<td>0.5% Ga</td>
<td>1.285</td>
<td>1.397</td>
<td>1.282</td>
<td>1.322</td>
<td>0.066</td>
</tr>
</tbody>
</table>

*Nanocomposite characterisation*

The presence of NPs in the AgNP and CuNP coated glass slides was successfully confirmed in the SEM images (see Figure 1). Well dispersed spherical NPs having diameters in the range 42 - 159 nm, were observed on the surface of AgNP coated glass slides. Although NPs were present in the CuNP samples, on visual inspection it is apparent the average particle size was much larger, in the sub-micron scale. The size difference noticed between the AgNPs and CuNPs may explain the significant difference in migration for both samples. The irregular shape of the sub-micron particles made it difficult to obtain a size distribution using the Fiji programme. As a result it was not possible to identify the proportion of particles which exist at the nano-scale.

![Figure 1. SEM images of a) AgNP/PS-b-PEO and CuNP/PS-b-PEO coatings.](image)

**Conclusions**

The size and concentration of AgNPs, CuNPs and GaNPs in a novel packaging surface coating were characterised and quantified successfully using SEM and ICP-AES techniques. Although the migration observed for each of the novel nanocoated samples far exceeded European Commission regulatory limits, the results suggest that the AgNP coating technique has the greatest potential of the three nanoparticle coatings to be developed into a packaging material. With further engineering of the composite packaging material and NP application process the antimicrobial efficacy may still be substantial while reducing migration below regulatory limits.

**Acknowledgements**

This work was funded under the Food Institutional Research Measure (FIRM) as administered by the Irish Department of Agriculture, Food and the Marine.
References


A NUMERICAL APPROACH TO INTERPRETING UNCERTAINTY ASSOCIATED WITH QUALITY CONTROL FOR CRONOBACTER SPP. IN POWDERED INFANT FORMULA

Friedrich von Westerholt, Francis Butler
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland

Abstract

Microbiological Criteria (MC) are an important tool with regards to producing a safe product in the food industry. Cronobacter spp. (formerly Enterobacter sakazakii) in powdered infant formula (PIF) has in the past been associated with illness and deaths in neonates. The sampling plans associated with MCs need to provide a high level of protection to insure a safe product. A Bayesian inference model was used to quantify the uncertainty associated with various sampling plans, both in the event of zero defective samples, and for one defective sample. The results portray an increase in protection in direct relation to the increase of sample numbers or sample size.

Introduction

Cronobacter spp. (formerly Enterobacter sakazakii) is an opportunistic pathogen widely associated with powdered infant formula (Healy et al. 2009, Yan et al. 2012). Its high mortality rate in neonates makes it a pathogen of concern for the PIF industry. Jongenburger (et al. 2011) has discussed the heterogeneous distribution of Cronobacter spp. in powdered infant formula (PIF). Heterogeneous distribution has a marked influence on the public health risk (Jongenburger et al. 2011). It has been established that clustering of pathogens occurs quite commonly in PIF (Habraken et al. 1986). The size of these clusters varies, however, their main relevance to sampling plans is that it is clusters which trigger the detection of the pathogen in presence/absence sampling schemes. Microbiological Criteria (MC) are one of the potential tools in evaluating a food safety risk management system. They can help decide the acceptability of a product or food lot, based on whether a specific microorganism is present or absent, and in what quantity (van Schothorst et al. 2009). The MC as specified under the Commission Regulation (EU) 2073/2005 (FSAI 2015) for PIF are absence in thirty 10g samples. The (ISO 2006) is used for Cronobacter spp. detection as part of the MC.

Because of the EU MC, PIF manufacturers carry out a considerable amount of quality control (QC) monitoring for Cronobacter spp. Historically, manufacturing companies have had periods of high incidence of detection, but with the introduction of enhanced biosecurity and cleaning processes, levels have reduced. However, sampling by its nature only tests a very small proportion of the total production and there is always the possibility of defective material slipping through. A Bayesian approach allows the possibility of quantifying the uncertainty associated with a test outcome (including a non-detect) to give a more realistic understanding of the true level of the pathogen that may be in the material depending on the test outcome. The Bayesian inference is the use of Bayes’ theorem for using data to improve an estimate of a parameter (Vose 2008).

The objective of this study is to use a Bayesian approach to characterise the uncertainty associated with interpreting a test result typically arising from ongoing commercial monitoring of Cronobacter spp.

Materials and Methods

A Bayesian approach was used to investigate the uncertainty associated with Cronobacter species in the event of both zero and one defective samples. The Bayesian inference is the use of Bayes’ theorem for using data to improve an estimate of a parameter (Vose 2008). An excel spreadsheet (Table 1.) was created to run the Bayesian model. An uninformed prior, treating all values of
clusters/tonne as equally likely, (Column D) was used as part of the Bayesian methodology. The parameters used were the number of samples (n), the number of defective/positive PIF samples (s), and the sample size (m). These were varied depending on the number of samples undertaken per batch, the sample size, and the number of defective samples in the batch (in this case 0 or 1).

A Poisson distribution was assumed for the distribution of the probability of the clusters/tonne being greater than zero (Column E). The Poisson distribution supplied the probability parameter for the binomial equation (Column G) to find the likelihood of all n tests being zero, using the binomial to evaluate the likelihood of \( \theta \) clusters/tonne with number of successes being zero or one, where the probability of success is given by the probability of detecting at least one positive (column E). A Bayesian posterior probability was created by multiplying the likelihood of each discrete possible concentration of clusters per tonne (Column B) by the uninformed prior. The posterior was then normalised by dividing it by the sum of all posteriors. The normalised posteriors present a confidence value for each discrete concentration value of clusters per tonne.

**Table 1: Bayesian approach for the uncertainty of *Cronobacter* in PIF in regards to sampling plan**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>29</td>
<td>30</td>
</tr>
<tr>
<td>31</td>
<td>32</td>
<td>33</td>
<td>34</td>
<td>35</td>
<td>36</td>
<td>37</td>
<td>38</td>
<td>39</td>
<td>40</td>
</tr>
<tr>
<td>41</td>
<td>42</td>
<td>43</td>
<td>44</td>
<td>45</td>
<td>46</td>
<td>47</td>
<td>48</td>
<td>49</td>
<td>50</td>
</tr>
<tr>
<td>51</td>
<td>52</td>
<td>53</td>
<td>54</td>
<td>55</td>
<td>56</td>
<td>57</td>
<td>58</td>
<td>59</td>
<td>60</td>
</tr>
</tbody>
</table>

**Results and Discussion**

Figure 1 shows the confidence interval using Bayesian inference associated with zero defective samples detected in a batch of PIF depending on sample weight and number. For all sampling plans the most likely outcome is zero. However values can be as high as 4000 clusters/tonne, depending on the sampling plan. The results show that the uncertainty is lowest for the 2 x 500g sampling, followed closely by the 90 x 10g sampling. The highest uncertainty occurs for the 30 x 10g sampling, just behind the 1 x 500g sampling. These results suggest very strongly that increasing either the amount of samples, or increasing the sample size, will result in a higher confidence in the product safety.
Figure 1: The confidence values for various quantities of sampling in the event of 0 positives.

Figure 2 shows the confidence interval in the case of one defective sample being detected. In this case the probability of zero clusters in the batch being present is zero resulting from the fact that one cluster was detected. The higher the spread of the curve, the higher the uncertainty as to how many clusters there are. The $90 \times 10g$ sampling gives the highest confidence ahead of the $2 \times 500g$ samples. The $1 \times 500g$ sampling has the highest uncertainty, just ahead of the $30 \times 10g$ sampling. In this case it appears that higher quantities of samples are beneficial, even in events where the total amount of product sampled is slightly lower. This can most likely be explained by the fact that one sample was defect. Bearing in mind that the MC for PIF is a presence/absence test, more samples give more information, than few do.

Figure 2: The confidence values for various quantities of sampling in the event of 1 positive.
Conclusions

Irrespective of the sampling plan being used, a zero detect does not imply that the batch is free of microbiological contamination. The Bayesian analysis demonstrates that the uncertainty associated with the existing EU MC requirement for thirty by 10 g samples is unacceptably high. The Bayesian analysis demonstrates that for better confidence in the sampling plan, either a higher sample number or higher sample weight is required.

Acknowledgements

This project was part financed by the Irish Department of Agriculture, Food and the Marine under the Food Institutional Research Measure.

References


SEPARATION OF DAIRY POWDERS BY NEAR INFRARED SPECTROSCOPY USING UNSUPERVISED PATTERN RECOGNITION METHODS

Eanna McHugh, Colm O’Donnell
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

The rapid analysis of products is critical for the optimisation and control of dairy powder production. The potential of Near Infrared Spectroscopic methods, combined with chemometrics, to separate heat treated whey protein powder groups was assessed using the near infrared region from 800 – 2400 nm. The unsupervised pattern recognition methods were used to analyse spectral data. Principal Component Analysis achieved clear visual separation of the heat treated groups after 2nd derivative data pre-treatment. Ward’s method cluster analysis of the raw data was 100% accurate separating the samples into 4 groups. The results indicate that NIR and chemometrics could be used to distinguish between sample groups of different heat treatments.

Introduction

Value added products and by-products such as Whey Protein Powder and Infant formula have become a major component of the Dairy Industry. The EU milk quotas were abolished in April 2015. This will cause strong international competition among EU member states in obtaining export markets. Dairy processing companies will require the most efficient manufacturing of products. Critically the processors will require the ability to implement rapid, effective and transparent systems to achieve control of and confidence in the specifications and properties of the powder based products.

Process Analytical Technologies have been extensively used in the Pharmaceutical Industry to verify the quality and integrity of the process chain. The US Food and Drug Administration (FDA) define PAT as a method to design, analyze and control the manufacturing process improving quality and control of the products (Munir et al. 2015). Applications within the Pharmaceutical Industry include blend and content uniformity and overall product quality control (Sarraguça and Lopes 2009). Studies have been carried out on the feasibility of applying NIR as a PAT within the Dairy Manufacture Industry (Kawasaki et al. 2008; Wu et al. 2008).

Chemometric modeling is used to interpret the data obtained from PAT methods such as a Near Infrared spectroscopy. The results obtained are heavily dependent on the chemometric and multivariate algorithms used to interpret the data (Guo et al. 1999)

The objective of this study is to evaluate unsupervised pattern recognition methods for the separation of dairy powder ingredients subject to varied levels of heat treatment using NIR.

Experimental Methods

Sample Preparation
Whey protein concentrate (WPC) batches were heat treated at different temperatures to achieve sample groups of different chemical compositions. 7 batches of WPC were prepared for analysis. Two batches at each of the temperatures, 72°C, 95°C and 115°C were prepared. One batch received no heat treatment as a control. Three samples from each batch were tested resulting in 21 samples.
Spectral Data Acquisition

The 21 samples were extracted from the sealed packages stored at room temperature (18-22 degrees Celsius). Each sample was then placed in the NIRSystem scanning pod. The samples were then scanned using a using NIRSystem 6500 (NIRSystem Inc., Laurel, MD, USA.) Spectra were recorded over the range of 400-2500nm in reflection mode (2 nm resolution). The NIRSystem was linked up to a PC running WINISI (Version 1.04; Infrasoft Int., State College, PA, USA). This software was used to record, convert and export the data signals. The data was exported as both .cfl and .jcm formats.

Pre-treatment of Data

The data set was subject to 11 point, 2nd order polynomial Savitzky-Golay smoothing to be used as the control sample set. This sample set was then subject to Normalization, Standard Normal Variate, 1st Derivation and 2nd Derivation pre-treatment methods. The 1st Derivation was conducted using an 11 point, 2nd order polynomial filter. The 2nd Derivation was conducted using a 21 point, 2nd order polynomial filter. A number of combinations of pre-treatment methods were trialled.

Data analysis

The data was extracted and imported into the Unscrambler X software (v10.2, CAMO Software AS, Oslo, Norway) for analysis. The spectral data for analysis ranged between the wavelength range of 800 and 2400. Principal Component Analysis was conducted on the raw spectra and each of the pre-treated data sets. Plot of the Scores and Loadings were used to identify separation between the class groupings and the wavelengths that influenced such groupings. Cluster analysis was conducted using Complete linkage and Ward’s method.

Results and Discussion

Separation of Sample Groups by Principal Component Analysis (PCA)

Principal component analysis of each of the data sets resulted in good separation between samples subjected to heat treatment and the control. PCA after SNV, Normalisation and 1st derivation pre-treatment methods failed to separate the samples that were subject to 95°C and 115°C heat treatments.

![Figure 1: PCA Scores plot (2nd Derivative)](image)

Figure 1b shows that 2nd derivation pre-treatment resulted in clear separation of all groups. A number of combinations of pre-treatment methods were trialled. No improvement on 2nd derivation was found.
The loadings plot of the SNV show that the 1940 nm variable is important to the model. The first two loadings accounted for 99% of the spectral variance. It is the wavelength of greatest variance. For each of the PCAs conducted 1940 nm was important for the separation of the sample groups. This was expected as heat treatment will greatly affect the moisture content and 1940 nm is related to the stretching and deflection of the O-H bonds of H$_2$O (Reh et al. 2004). There are a number of other peaks and troughs identified by the series of loading plots showing that the chemical properties of the powders were changed by the heat treatment.

*Cluster Analysis*

The most successful method was Ward’s Method, successfully grouping each sample correctly. The Complete Linkage method failed to correctly group the entire sample set.

The relative distances are of interest. The samples that were subject to high heat treatment are more closely related to the control group than the low heat treatment group. This may be due to the change in chemical composition due to heat treatment.
Conclusions

It is evident that through NIR and chemometric techniques separation between heat treated sample groups can be achieved. The unrecognised pattern recognition techniques achieved good clustering. Through PCA and 2nd derivative data pre-treatment each heat treatment group was visually identifiable. Ward’s method cluster analysis was successful in the grouping of the samples. From the results achieved, it is concluded that NIR and unsupervised pattern recognition methods have the potential to separate sample groups of different heat pre-treatments. Information can be extracted by NIR and chemometrics, therefore there is a potential or such methods as PAT for the dairy ingredient industry.

Acknowledgements

The author acknowledges the assistance of Prof. Gerard Downey for the guidance and use of the facilities at Teagasc Food Research Centre, Ashtown.

References

PUBLIC AND ANIMAL HEALTH RISKS ASSOCIATED WITH SPREADING THE PRODUCTS OF ANAEROBIC DIGESTION

John Meehan and Enda Cummins
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Anaerobic digestion facilities can only be considered successful if they produce a significant energy output. Optimising the efficiency of the technology involves using biodegradable feedstock’s of the correct composition. These organic feedstock materials can come from a variety of waste streams including animal by-products, food waste, municipal solid waste and green matter, all of which can be mixed to achieve the best biogas output. Given the diverse range of organic materials that can be utilised in anaerobic digesters, it is critical to know what risks are associated with the by-product of the treatment process. Digestates could potentially contain pathogens and/or chemicals that will cause harm to both humans and animals alike. Therefore, assessment of the potential hazards associated with both the feedstock and ultimately the digested material is essential in determining whether the products of anaerobic digestion are of risk to the public and/or animals health when the material is land-spread.

Introduction

Anaerobic digestion (AD) breaks down biodegradable material through a collection of complex biochemical reactions which are carried out, in the absence of oxygen, by microorganisms (Mata-Alvarez, 2003). The process generates a gas known as biogas. Biogas is a renewable energy source that is primarily made up of methane (CH₄) and carbon dioxide (CO₂) (Weiland, 2009). Combined heat and power (CHP) plants can burn this renewable fuel to generate heat and power, usually in the form of electricity. The biogas can also be upgraded to biomethane, which is equivalent to natural gas due to its purity, through a process called scrubbing (Kapdi et al. 2005). AD also produces a semi-solid residue called digestate (Chandra et al. 2012). This material is made up of nutrient-rich organic matter and is used as a fertiliser which is spread on agricultural land.

The technology is proven and the use of AD to treat organic waste thus producing biogas and a fertile digestate is increasing across Europe (Gong et al. 2011). AD is now recognised as a waste-to-energy process that simultaneously generates biogas while also serving as a waste management tool. The composition of organic feedstock can be derived from various waste streams including animal by-products (ABP), the organic fraction of municipal solid waste (OFMSW), forestry waste and even wastewater treatment plant (WWTP) sludge.

The EU has specified restrictions in relation to which organic wastes can be anaerobically treated in digestion facilities and the subsequent handling of the digestate. Regulation 1774/2002 determines the health rules concerning animal by-products which are not intended for human consumption. This legislation determines that the spent organic substrate of AD must be pasteurised to a temperature of 70°C or 90°C for at least 60 minutes. As thermophilic digesters are normally operated at temperatures much below this, usually circa 55°C, it seems extremely inefficient to expose the product to further thermal treatments of 70°C and above to ensure product safety. In carrying out a risk assessment of animal by-products, informed decisions can be made on whether or not these EU standards are too severe.

The objective of this study was to determine the health hazards associated with the spreading of anaerobic digestate of animal by-products.
Materials and Methods

Animal by-products

The typical composition of animal by-products going for AD in Ireland needs to be classified and quantified. As Irish legislation only permits Category 2 and 3 ABP to be sent for biogas production, the feedstock can contain a number of waste materials ranging from farmyard manure and parts of slaughtered animals to catering waste. The Department of Agriculture, Food and the Marine (DAFM) defines ABP as “…entire bodies or parts of animals, products of animal origin or other products obtained from animals, which are not intended for human consumption, including oocytes, embryos and semen…” (DAFM, 2014).

In 2014, Ireland produced in excess of 96,000 and 53,000 tonnes of Category 3 processed animal protein (PAP) and Tallow respectively (Kelly, 2015). It is also estimated that 37 million tonnes of animal manure is stored on Irish farms each year before final disposal through conventional land-spreading methods. As these significant volumes of material can be utilised in AD, their compositions need to be established to allow the risks associated with the final digestate product to be identified.

Figure 1: Potential Routes of Exposure to Microbiological and Chemical Hazards through Land-spreading of Contaminated Organic Materials
Pathogenic and Chemical Hazards

The risks related to the final product can be assessed when the aforementioned organic substrates have been identified. These will include all microbial, viral, zoonotic and chemical concerns that may put human or animal health in jeopardy. Table 1 details the main biological hazards associated with the organic feedstocks that can be used in the AD process.

Table 1: Biological hazards & effects of AD and subsequent land-spreading has on the pathogenic organism

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Gram</th>
<th>Respiration</th>
<th>Ana-aerobic</th>
<th>37°C</th>
<th>55°C</th>
<th>pH 7</th>
<th>Aerobic</th>
<th>Zoonotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacillus cereus</td>
<td>+</td>
<td>Facultative anaerobe</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>No</td>
</tr>
<tr>
<td>C. botulinum</td>
<td>+</td>
<td>Anaerobic</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>C. perfringens</td>
<td>+</td>
<td>Anaerobic</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Clostridium spp.</td>
<td>+</td>
<td>Obligate anaerobe</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>E. coli (EHEC)</td>
<td>-</td>
<td>Aerobic</td>
<td>X*</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>E. coli (IEC &amp; ETEC)</td>
<td>-</td>
<td>Facultative anaerobe</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. coli (EPEC)</td>
<td>-</td>
<td>Facultative anaerobe</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L. monocytogenes</td>
<td>+</td>
<td>Facultative anaerobe</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mycobacterium</td>
<td>NA</td>
<td>Aerobic</td>
<td>X</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Pseudomonas spp.</td>
<td>-</td>
<td>Obligate aerobe</td>
<td>X</td>
<td>O</td>
<td>O</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salmonella enterica</td>
<td>-</td>
<td>Facultative anaerobe</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shigella spp.</td>
<td>-</td>
<td>Facultative anaerobe</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staphylococcus</td>
<td>+</td>
<td>Facultative anaerobe</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parasites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryptosporidium</td>
<td>NA</td>
<td>NA</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Fungi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspergillus spp.</td>
<td>NA</td>
<td>Facultative anaerobe</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Viruses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hepatitis A</td>
<td>NA</td>
<td>NA</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Norovirus</td>
<td>NA</td>
<td>NA</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BSE</td>
<td>NA</td>
<td>NA</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

X* indicates the microbial inactivation of bacteria but does not indicate that spores have been destroyed

Anaerobic Operating Conditions

There are two main types of temperature regimes that are utilised in AD; mesophilic and thermophilic which operate at temperatures of approximately 37°C and 55°C respectively. Two-phase AD, where combinations of both regimes are used to maximise the effectiveness of the process, will be modelled for this risk assessment. The digester will be operated at ideal pH conditions of around 6.8 – 7.4 and have a hydraulic retention time (HRT) of 30 days.

It should also be mentioned that in table 1, above, the inactivation of the pathogens has not been considered for a time-temperature equivalence. For instance, the vegetative cells in Clostridium botulinum can be rapidly killed at temperatures above 55°C but could equally be destroyed at lower temperatures with an equal time-temperature equivalence. However, to ensure microbial safety, the HRT has not been considered when determining whether or not the thermophilic temperatures inactivate the respective pathogens.
Model Development

A risk assessment model is to be developed which will evaluate the expected hazards, taking into account the operational conditions of the digester, associated with the nutrient-rich digestate. Furthermore, a model will be developed to assess the risks associated with the digestate when it has been applied to agricultural land. This model will evaluate the inactivation of pathogens and other harmful substances through aerobic conditions and/or UV inactivation.

It is also intended that variability and uncertainty will be considered in the risk assessment with probability density distributions and Monte-Carlo simulation approaches the preferred technique used to evaluate such changeability. This, again, will ensure discrepancies are kept to a minimum and accuracy within the results is maintained.

The model will then compare the simulated results with regulation limits to assess whether the digestate is of harm to the environment, animals and ultimately humans. Observations will be made on the outcome of these assessments which will result in the formulation of recommendations.

Results and Discussion

Based on the results the maximum permitted regulatory hazard and exposure levels, with regards to the examined pathogens, will be investigated. The author is also conscience to analyse the results with respect to the limitations of the approach adopted.

Conclusions

Upon assessing the risks associated with the spreading of digestate from the AD of animal by-products, it health issues of concern to both animals and humans will be determined. Although, organic matter may be fed into the AD which contains pathogens, parasites and chemicals there are a number of hurdles which must be overcome in order for the material to be classified as harmful to both animals and humans alike. These hurdles inactivate microorganisms and thus dangerous hazards may be exposing to environments in which they cannot survive.

Acknowledgements

The authors would like to thank PJ Kelly and Melanie Farrar from the Department of Agriculture, Food and the Marine for all their time and assistance.

References

Department of Agriculture, Food and the Marine (2015) Approval and Operation of Biogas Plants Transforming Animal By-Products and Derived Products in Ireland, Milk and Meat Hygiene/ABP/TSE Division, Portlaoise, Co.Laois.
AUTHENTICITY VERIFICATION OF AN ALCOHOLIC BEVERAGE USING NIR SPECTROSCOPY

Abhishek Pathak and Colm O’Donnell
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract
Aged Whiskies, wine and beer are most liked and famous around the world but counterfeiting of these aged alcoholic beverages is seen as major problem throughout the world. As it is difficult for a consumer to authenticate the age claim on retail bottles, some malapert trader’s sell lower quality or aged liquors calming it as high quality or well matured liquor. Fast, non-destructive and reliable method to authenticate the quality of liquor is needed in the present market to fight against unscrupulous traders and protect consumer interests for the desire of high quality alcoholic beverages. Using NIR spectroscopy (near infrared spectroscopy) to reach those expectations of consumers is a new approach for verification of authenticity and classification of alcoholic beverages. To perform an evaluation of techniques three measures were assessed specificity, accuracy and sensitivity.

Introduction
A very essential task in the liquor industry is standardization of quality parameters. Composition of liquor is ethanol and water as a major composition of 98% plus some inorganic elements and ingredients responsible for fragrance such as ester. Counterfeiting and falsification of high quality liquor is increasing because of high demand. These counterfeit liquors are prepared by diluting original liquor with water, ethanol or by a mixture of water, alcohol and aroma.
To verify the liquor authenticity methods are depend on different composition data (Pontes, 2006; Cozzolion, 2009) but all method include a pre-treatment process of distillation which is time consuming and laborious. NIR spectroscopy has the advantage of simple operation and fast collection of spectra information and low cos. (Xiaoying, 2008; Duan, 2012). Absorption of light at different wavelength in Near-infrared region and correlation between chemical properties, measured by transflectance and reflectance is a base of NIR spectroscopy technique. Development of a model is crucial to the availability of NIR- based applications. To improve the performance of NIR efforts have been done in recent years to develop a method.

The objective of this study was to authenticate and classify the alcoholic beverage on the basis of adulteration or adulterant by using NIR spectroscopy with Chemometrics

Materials and Methods
The method used to verify the authenticity of liquor should be fast and non-destructive more over it should be fast in obtaining and analysing data with minimum error under effective cost. Combining NIR with Chemometric means performing calculations on the measurement of chemical data like pH, calculation by measuring ion activity of hydrogen to interpolation of spectrum (Anon., 2015). Due to complexity in composition of alcoholic beverages chemometric techniques which are normally applied for data treatment are principle component analysis (PCA), Soft independent modelling of class analogy (SIMCA), Hierarchical cluster analysis (HCA), Canonical analysis (CA), Discriminant analysis (DA), Principal component regression (PCR) and partial least square analysis (PLS). A strategy proposed in this study of verification of authenticity of alcoholic beverage is PCA and SIMCA. This is applied as screening analysis to verify adulteration of alcoholic beverages. That is used as a prior step to condition the sample to a deeper analysis when a positive result for adulteration is obtained. The proposed methodology follows that of (Pontes 2006).

SIMCA is a chemometric technique which classifies samples based on PCA models (Flaten 2004) explain for a given group or class of samples, a PCA model that delimits a region of the multidimensional space. The PC-s in the PCA model and the limits established for these PC-s define the model of class by SIMCA (K.R Beebe). The distance between the sample and the projection of PC axis(Y in fig 1) and the distance between the limit of class(X in fig 1) and the projection of the sample
in PC axis is calculated to verify if an unknown sample belongs to a class defined by the PC_s model previously. This sample is classified as belonging to the modelled class if its variance present a value smaller than a critical value for the class. This done by following calculation and equations

Firstly, the value \( z^2 \) is calculated by using eq1.

\[
z^2 = \frac{1}{x^2 + y^2}.
\]

Secondly, \( Z^2 \) is divided by the variance of the class to obtain calculated value, \( F_{calc} \). Then F test is used to compare \( F_{calc} \) to a reference value, \( F_{crit} \), calculated from the training set. If \( F_{calc} \) goes smaller than \( F_{crit} \) the unknown sample can be classified as belonging to class (K.R Beebe)

![Figure 1: Forecast by SIMCA model.](image)

1- Samples

Pure Whiskey, Rum, Vodka, Brandy samples purchased from local market were used as training sets to construct PCA and SIMCA models. These samples are adulterated by deionized water, ethanol 99.8%, in the level of 5%V/V and 10%V/V in the pure beverage. It was considered that the developed methodology is proposed for screening analysis and not for quantitative assays, the limit of 5% was arbitrarily chosen as the inferior limit to analyse the beverages. If a more accurate assay is desired another methodology needs to be used.

2- Equipment’s

A spectrum GX FTIR spectrophotometer was to record the spectra of the alcoholic beverages. It was equipped with a lab-made quartz flow-cell and a microcomputer dual core 1.8GHz processor was used for data analysis.

3- NIR spectra acquisition

Before the acquisition of spectra samples were conditioned in plastic containers and preserved at 24°C with 41% of air relative humidity for at least one hour. At first, a blank spectrum is recorded using an empty flow cell. Then each sample is aspirated and its spectrum is registered from 1100 to 2500 nm with 2 cm resolution. Each sample spectrum used in the construction of PCA and SIMCA model corresponds to a mean of 16 scans.

4- Software

PCA and SIMCA were performed using unscramble 7.5 software (CAMO)

Results and Discussion

Spectra which may be registered for all the analysed samples of alcoholic beverages is shown in Fig 1 (Pontes (2006). The first OH overtone of water and ethanol occur at 1454nm. The second overtone of CH stretching and CH with aromatic group combination band registered at 1690nm. The first CH stretching overtone occur at 1790nm. The strong band is characteristic of alcoholic beverages occur at
1950nm. Vicinage of 1160nm, aromatic and carbonilic compounds exhibits its second overtone absorption (Murray 1996)

![Figure 2: Spectra of all the alcoholic beverage samples analysed for this study.](image)

1- Pre-treatment of data

To aggravate the problem of systematic variations in the base-line, derivative spectra were calculated with Savitzky-golay filter (K.R Beebe 1998) shown in figure 3, by using a 21 point window and second order polynomial. In order to create a data base with characteristic analytical signals of each beverage pure alcoholic beverages were analysed. It was necessary to use the chemometric methods of pattern recognition and classification (PCA and SIMCA) to characterize each group because all pure sample of beverage present very similar spectra profile (Flaten 2004; Pontes 2006).

![Figure 3: Derivative spectra of all samples of alcoholic beverages in the spectral region from 1100 to 2500 nm after smoothing by Savitzky-Golay second-order polynomial fitting.](image)

To construct these model a cross-validation method was used (Beebe, 1998). After modelling the training set by PCA it was observed that two PC-s were enough to characterize whiskey and vodkas sample while for brandy and rum three and four PC-s were sufficient to be used in SIMCA for authenticity, verification will be defined by these PC-s (Pontes 2006)

Result will be based on the score plot for each class of alcoholic beverage

Conclusions

For the verification of authenticity of alcoholic beverages a new strategy is proposed in this study by using NIR spectroscopy and PCA-SIMCA chemometric methods. There will be no requirement for pre-treatment of samples since a very small amount of sample is used in the analysis. To verify the authenticity and adulteration of alcoholic beverages this strategy is highly suitable as regents to carry out an assay are absent and it has high sampling throughput.
Acknowledgements
The author would like to thank Dr Gerard Downey, Teagasc Food Research Centre, Ashtown Dublin 15, for all his advice and help.

References


EXPOSURE ASSESSMENT OF ACRYLAMIDE FOR IRISH CONSUMERS

Aishwarya Sivaraman, Enda Cummins
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Acrylamide is a chemical that has been detected in a wide range of food products; it is formed due to frying, roasting or baking of starchy food products. The presence of acrylamide in food has been a large concern due to its toxic nature, and it has been classified by the WHO/IARC as ‘probably carcinogenic for humans’. The purpose of this study was to test a given hypothesis which says ‘Human exposure to Acrylamide through food products is minimal for Irish consumers and does not represent a significant health threat’. To test this hypothesis a typical Irish diet was considered and the acrylamide content in the most important food products was obtained from the European Union database for Acrylamide levels in food. A risk assessment model was developed using the Monte Carlo simulation modelling. From the Exposure assessment it was found the total Exposure to Acrylamide for ages 18 to 64 is 0.58µg/kg bw/day and 0.45µg/kg bw/day for ages 65 and above.

Introduction

Acrylamide (H₂C=CH–CO–NH₂, CAS no. 79 06 1) is the monomer, from which polyacrylamides are synthesised. In 2002, Swedish scientists and Swedish National Authority reported that Acrylamide is found in various fried, deep fried and over baked foods, but not in boiled foods. Regularly consumed foods such as chips, fries, bread, coffee etc. contain acrylamide. Due to the potential for exposure to acrylamide, effects of acrylamide in cells, tissues of animals and humans have been extensively studied. It causes tumours in laboratory rats and has been found that it is a neuro-toxin in humans and may affect reproductive processes.

Acrylamide was found to be formed as a side product of the Maillard reaction. The Maillard reaction is the complex chemical reactions that occurs during processes such as frying and roasting, which largely determines the colour, flavour and texture of cooked foods (FSAI, 2009). The key constituents of food initiating the Maillard reaction and giving rise to high level of acrylamide in food are amino acid asparagine, glucose and fructose (reducing sugars).

A number of risk assessments have been carried out on acrylamide and it has been suggested that efforts should be made to reduce the level as much as possible (FSAI, 2009). This study was carried out by synthesising existing data in relation to acrylamide formation in food products and evaluating the likely human health risk. To assess the Irish population exposure to acrylamide present in food, data was obtained an exposure assessment was conducted to determine the level of exposure to acrylamide for two age groups, 18 to 64 and 64 and above. This assessment was done using the Monte Carlo Simulation modelling in Microsoft Excel. To do the Monte Carlo Simulation the RASP (Risk Assessment Software Package) was used, this software is a fully functional Monte Carlo simulation tool for academic purposes.

The objective of this study was to determine the levels of acrylamide in various food products consumed by Irish consumers and evaluate the likely food consumption of the different food products in males, females and children.
Materials and Methods

Food Sample Selection

According to several databases such as European Union’s acrylamide monitoring database, the United States Food and Drugs Administration’s acrylamide survey data and the WHO’s Summary Information and Global Health Trends database, it is found that acrylamide is most prevalent in fried potato products (French fries, chips and potato crisps), cereals, crisp breads, biscuits, other bakery wares and coffee. Hence, the food sample selection was mostly focused on these products. For all the food products selected consumption data was obtained from the FSAI (Food Safety Authority of Ireland) and National Adult Nutritional Survey database. The foods have been selected based on staple foods in the Irish diet which includes potatoes, breads and dairy products which is consumed by all age groups. The age group was divided to 2, 18 to 64 years, number of participants were 1,274 and for the population greater than the age of 64 the number of participants were 226 (National Adult Nutrition Survey Summary Report, 2011). The acrylamide data was obtained from European Union Database of Acrylamide levels in food. This database as a whole has found appreciation especially for exposure and risk assessment studies.

The various food products considered for this exposure assessment are given below in the table 1.

<table>
<thead>
<tr>
<th>Food Product</th>
<th>Level of acrylamide (µg/kg)</th>
<th>Food Intake (g/day)</th>
<th>18-64 years (n=1274)</th>
<th>&gt;=65 years (n=226)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
</tr>
<tr>
<td>Potato crisps</td>
<td>528</td>
<td>5</td>
<td>4215</td>
<td>66</td>
</tr>
<tr>
<td>Breakfast Cereals</td>
<td>70</td>
<td>5</td>
<td>1649</td>
<td>39</td>
</tr>
<tr>
<td>Biscuits &amp; crackers</td>
<td>145</td>
<td>4</td>
<td>3324</td>
<td>21</td>
</tr>
<tr>
<td>White bread</td>
<td>50</td>
<td>5</td>
<td>1987</td>
<td>66</td>
</tr>
<tr>
<td>Coffee</td>
<td>320</td>
<td>79</td>
<td>1188</td>
<td>271</td>
</tr>
<tr>
<td>Chocolate confectionary</td>
<td>161</td>
<td>161</td>
<td>161</td>
<td>20</td>
</tr>
</tbody>
</table>

Analysis

The method of analysis was using Monte Carlo Simulation in Microsoft Excel. The WHO estimates that the human exposure to Acrylamide should not exceed 1 µg/kg body weight per day and high exposure is regarded as 4 µg/kg body weight per day. Based on the estimation of WHO, the Monte Carlo Simulation was conducted for the data obtained from various databases as tabulated above. Six food product samples were considered as they are the staple Irish food and the Monte Carlo Simulation was performed using the Risk Assessment Software Package (RASP) to find the exposure to Acrylamide by the Irish population from ages 18 to 64 and above 64. The data was obtained from (National Adult Nutrition Survey Summary Report, 2011) and (European Union Database for Acrylamide levels in Food, 2007).

Exposure Estimation

The RASP (Risk Assessment Software Package) was used to estimate the exposure of acrylamide with the data collected from the above mentioned databases. For each age group considered a Monte Carlo Simulation was performed with 1,000 iterations and only consumers were considered in the sample selection. Monte Carlo Simulation is a complex stochastic technique used to solve a wide
range of mathematical problems. The parameters in Table 1 were the inputs for the simulation performed.

Results and Discussion

Analytical Results

The model resulted in two output distributions for the 2 age groups selected; this was used to predict the acrylamide exposure for the selected population groups in Ireland. The results obtained from the exposure assessment indicated that the exposure to acrylamide for Irish consumers is minimal and does not exceed the limit provided by the WHO. The probability density distribution was obtained from the exposure assessment and the exposure to acrylamide for the age group 18 to 64 was found to be 0.58 µg/kg bw/day and for the age group 65 and above it was 0.45 µg/kg bw/day. The exposure to acrylamide for both the population groups was found to be well below the WHO limit. The high exposure level estimated by WHO is 4 µg/kg bw/day, it was found that the probability of exceeding this limit by both the age groups was nil.

Figure 1: Probability density of acrylamide exposure for ages 18 to 64.

Figure 2: Probability density of acrylamide exposure for ages 65 and above.
Conclusions

The Model in this study indicated that the exposure to Acrylamide for the Irish consumers is minimal, thereby proving the Hypothesis, although the study was only conducted for two age groups and not children, male and female population separately. The data for this exposure assessment was availed from various databases and the result was obtained for the two age groups mentioned, using the Risk Assessment Software Package to perform the Monte Carlo Simulation. The acrylamide exposure was well within the estimated level by the WHO for both age groups, but the age group of 18 to 64 are exposed to acrylamide more than the older population according to this model. For the 18 to 64 age group the exposure was found to be 0.58 µg/kg bw/day and for ages 65 and above it was found to be 0.48 µg/kg bw/day. The distribution for the acrylamide level in the food sample selected was obtained. The model developed in this study is a basic model and does not include a wide range of sample as well as the population; further study is being done in this area.

Acknowledgements

The author acknowledges the free use of RASP (Risk Assessment Software Package, by Dr. Enda Cummins, UCD School of Biosystems Engineering).

References


PROCESS ANALYTICAL TECHNOLOGY IN MILK POWDER MANUFACTURE

Ashwin Sridhar and Colm O’Donnell
School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract
The conventional method for testing food is by separating a part of the processed food and testing them for their sensory and nutritional properties. This process is commonly called as off-line monitoring. But of late the off-line monitoring have met many disadvantages, mainly due to time constraints. The experts found this method very slow in an industry as dynamic as the food industry. Process Analytic Technology is a system for designing, analysing and controlling manufacturing through timely measurements (during processing) of critical quality and performance attributes of raw and in-process materials and processes, with the goal of ensuring final product quality. Process Analytic Technology (PAT) is primarily used in the pharmaceutical industry but now is extended to the food industry as the consumers favour consistency of organoleptic characteristics. The fact that the food industry is increasingly globalised also contributes to the cause. The most important reason was the need for a robust system to guarantee consistency and safety of the product.

Introduction
Quality-by-Design is well established in the development and manufacture of pharmaceutical drug substances. PAT tools are routinely applied to develop a greater understanding of the process design space under Quality-by-Design framework. PAT has been used extensively in the dairy industry, mainly in the manufacture of milk powder to achieve compositional specification, avoid chemical contamination, and improve process and physical stability. The application follows a procedure: identify the critical process parameters followed by choosing the appropriate process analytical technology for each. Systems need to measure, monitor and control the process thereby ensuring the quality and safety of the finished product. Timely measurements are taken by probes or sensors operating on a specific principle such as laser, UV light, infrared etc. whose spectral properties are known. This knowledge of the absorption spectra can be converted into data. The probes transmit data by the use of fibre optic cables which can stretch over a long distance. The information from the signals are collected using multivariate data analysis. The goal of this study is to monitor, measure and control the milk protein concentrate (MPC), protein denaturation and milk reconstitution using Focused Beam Reflectance Measurement (FBRM) which uses lasers as the light source.

Materials
The FBRM is a tubular device with a laser source, a monochromatic beam splitter, a probe tube and a sapphire window. Fibre optic cables of 3 meters length is connected to the equipment via the computer where the data is collected. Any computer with the ‘UnscramblerX’ software can be used. The sample used is milk powder stored in canning jars to avoid moisture at room temperature. Five types of industrial spray-dried MPC powders with different protein contents were obtained. The heating and storage history were given by my mentor. The samples are to be categorized A, B, C, D and E respectively.
Milk Protein Concentrate (MPC)
Protein is one of the major components as well the most valuable of dairy products. Milk products rich in protein have been customized to meet specific requirements in nutritional and functional properties, for instance in bakery products, ice-cream, beverages, energy drinks etc. Protein is a heat sensitive material and during drying, structural and physical changes due to protein denaturation can occur. MPC is known to have a relatively poor dissolution properties (40-90 wt. %). MPC is known to have a relatively poor dissolution properties. Mostly MPC was tested off-line, but FBRM provides the ability to monitor in situ the changes over different concentrations.

Procedure:
The experiment is carried out in a 600 ml vessel equipped with an overhead stirrer rotating at 600-1000 rpm. The testing temperature is adjusted using the water bath. For each test 10 g of MPC powder will be measured and poured into the beaker containing 500 ml distilled water. The FBRM is also inserted into the beaker as shown in the figure. The data from FBRM will be collected using IC FBRM software for every 20 seconds with a measurement duration estimated to be one hour. After an hour. The insolubility test will be carried out and insolubility index (ISI) of the different MPC powders can be calculated using the following equation.

\[
ISI = \frac{M(\text{Tube+Sediment}) - M(\text{tube})}{M(\text{Tube+Solution}) - M(\text{tube})} \times 100\%
\]  

We have to note that the entire MPC can dissolve, given a long enough time but the consumers using the powder are mostly interested in ‘shorter’ time behaviour.

Results Obtained:
When the laser light in the FBRM struck the powder, the light is backscattered. This backscattered laser light is detected by the probe. As solubility is a relative measure that varies according to different testing conditions, it is necessary to define a physical measure for the solubility of MPC powders. Using FBRM, the mean chord length of the particles in suspension was used to quantify powder solubility. During the dissolution process, agglomerated MPC particles would gradually break down into smaller particles indicated by the decrease in chord length. A smaller chord length would imply a lesser amount of undisolved particles. The solubility result for the powder sample A was obtained.
The duration of each pulse of back scattered light is multiplied by the scan speed to calculate the chord length. The graph defines the solubility of sample powder A and each curve represents data plotted at a specific testing temperature. The mean chord length is used to estimate the solubility which is approximately 280µm.

**Expected Results:**
The solubility for MPC of the other four samples should be defined after which we establish dissolution profiles. FBRM could provide data such as the initial particle size and the relative particle counts. The initial particle size can be obtained by carrying the experiment at 0°C. The average of the last 10 minute readings can define the initial particle size. From the initial particle size, the relative particle size can be calculated using an equation. The chord length of original and supernatant of powders A-E at room temperature should be obtained which will determine the amount of dissolved and undissolved particles after centrifugation.

**Figure 2:** Chord length of the particles

**Figure 3:** Milk Composition for different samples
The absorbance vs wavelength plot is obtained from the information given by the probe. The higher peaks indicate the moisture content and the lower flat peaks indicate the lipid and protein level in the milk powder.

References


EFFECT OF HEAT TREATMENT AND STORAGE ON THE RECONSTITUTION PROPERTIES OF MILK POWDER

Xia Wang and Colm O’Donnell
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract
The reconstitution properties of milk powder are of particular importance to manufacturers and consumers. 18 milk powder (MP) samples from three different heat treatment histories (low, medium and high) and two different storage conditions (normal and accelerate) were tested for reconstitution using the Focused Beam Reflectance Measurement (FBRM). Higher temperature heat treatment and storage conditions affected the reconstitution properties of milk powder samples by increasing the dispersion of the final particle sizes.

Introduction
In the food industry, reconstitution properties of powdered dairy products are considerably important. Reconstitution of milk powder is a time consuming process and is significantly influenced by several parameters, such as protein and mineral content, heat treatment histories, spray drying temperature, reconstitution process and storage conditions of powder samples (Koh et al. 2014; McCarthy et al. 2014). Reconstitution or dissolution of food powder generally consists of several steps, i.e., wetting of powder particles, sinking, dispersing and particles completely dissolving in solution (Fang et al. 2008). In this study, final particle size of milk powder dispersions was used as the parameter of the reconstitution behaviour. An in-situ Focused Beam Reflectance Measurement (FBRM) was used as the tool to monitor particle size; and a reference technology laser diffraction particle size analyser was also used in this study. The objective of this study is to investigate the reconstitution properties of milk powder with different heat treatment and storage histories using a FBRM technology.

Materials & Methods
In total 18 milk powder (MP) samples with different heat treatment and/or storage histories were studied for the reconstitution properties. Table 1 shows the details of heat treatment temperature, storage duration and storage conditions.

<table>
<thead>
<tr>
<th>Storage duration / Heat treatment</th>
<th>MP1</th>
<th>MP2</th>
<th>MP3</th>
<th>MP4</th>
<th>MP5</th>
<th>MP6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month 0 -</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Normal</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Accelerate</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

All milk powder samples were reconstituted in deionized water to make a 300g solution with 12% total solid was held at 50°C in a 500 mL glass jacketed vessel with a recirculating chiller
fitted for temperature control. An overhead 4-blade impeller was used with rotating rate at 400 rpm. FBRM (model D600L, by Mettler Toledo) was placed in the vessel to monitor the reconstitution process. The data from FBRM were collected by iC FBRM program (Mettler Toledo), with the collecting interval set at 10 s for 30 min duration. All experiments were performed in triplicate and the reported values are the mean of the three experiments.

FBRM provides particle counts for the size ranges between 1 and 1000 μm, which divided the particle population into 5 groups, namely with the chord length less than 10 μm, 10–50 μm, 50–150 μm, 150–300 μm and 300–1000 μm (Fang et al. 2011). The median chord lengths (MCL, consider as particle sizes of milk powder dispersions in this study) calculated by the software were used to indicate milk powder reconstitution properties.

Milk powder samples were also dissolved in deionized water at 50°C for 30 min (total weight 100 g solution) using a magnetic stirrer with a water bath to control the temperature. The particle sizes of the milk powder dispersions were determined using a Mastersizer 3000 laser diffraction particle size analyser. Size measurements were recorded as median D50 and cumulative diameters D90 and D10 (McCarthy et al. 2014). However, different measuring system and particle size ranges (0.01–3500 μm) were provided by Mastersizer, which gave different final particle size from FBRM results, further discussed in results and discussion.

**Results and discussion**

Since all milk powder samples were agglomerate samples, as shown below in Figure 1, all milk powder reconstitution tests showed good repeatability; and it could also be found that the particle size exhibited a significant decrease in the first 30s rapidly and reached a plateau. For the next 29.5 min, mean particle size changes were normally less than 1 μm, which means the majority of milk powder dissolution occurred during the first period. Figure 2 also proved this, no significant difference could be found between particle size distribution at 30s and 1800s.

![Figure 1: Typical FBRM results of milk powder sample’s particle size change with time (triplicate tested)](image1)

![Figure 2: Typical particle size distribution results of milk powder samples at 30 and 1800s (triplicate tested)](image2)

Figure 3 below showed the comparison of FBRM and Mastersizer laser diffraction particle size analyser results, since they use different measuring systems and ranges, and different data analysis methods. FBRM reported 4.26 μm of median chord length for MP1 Month 0 sample,
while Mastersizer gave the $D_{50}$ of 0.7228 μm. Even with different values in the results, the same particle size change trend was found in our studies. Also, as shown in Figure 5 (left) and Figure 6, all FBRM and Mastersizer results were matched. In our case, Mastersizer was used as a reference method, which described and compares final particle size change trend; while FBRM results were used for particle size study.

**Figure 3:** Comparison of FBRM and Mastersizer results (sample: MP1 Month 0)

**Figure 4:** Storage temperature and duration effects on particle size distribution

**Figure 5:** Heat treatment effects on the final particle sizes (left) and particle size distribution (right)

Figure 5 (right) presented the heat treatment effects on the mean particle size and particle size distribution of milk powder samples, a higher temperature resulted in larger particle size. From the Mastersizer results, samples with low temperature heat treatment, the distribution chart appeared narrower than those with high temperature heat treatments. But there were no significant differences found on the FBRM particle size distribution results. Also, for samples with low heat treatment, one single large volume density peak appears on the chart, while as the temperature increased, a second volume density peak at larger size class becomes more clear, with increasing particle size and decreasing the reconstitution properties of milk powder samples.

The distribution changes on storage samples were not as significant as samples with different heat treatments. A small difference between fresh samples and aged samples can be found from figure 4 above, however, there was no difference between different storage temperatures. Figure 6 illustrated the storage temperature and duration effects on mean particle size for all milk powder samples. It is clear that particle size increased accordingly with increasing storage temperature for most of the samples (except MP5). However, MP5 with a lower
storage temperature appeared to have larger particle size than at the higher storage temperature. In the case of MP5 samples, the particle size of month 3, with normal storage, appeared abnormally high (over 4.40 µm). In order to understand it, other physical and chemical measurements would be required.

![Figure 6: Storage temperature and duration effects on final particle size (FBRM: median chord length and Mastersizer: D_{50})](image)

**Conclusion**

In this study, FBRM has been demonstrated as a useful tool to characterise milk powder reconstitution properties. Milk powder samples with higher temperature heat treatment presented relatively larger particle sizes after reconstitution. It was also found that for most of the samples, storage with higher temperature showed a higher influence on reconstitution properties.

**Acknowledgements**

The authors would like to thank the financial support from the Chinese Scholarship Council (CSC) and University College Dublin (UCD).

**Reference**


OPTIMIZATION AND CHARACTERIZATION OF ULTRASOUND ASSISTED EXTRACTION OF PHLOROTANNINS FROM A. NODOSUM

Shekhar U. Kadam and Colm P. O’Donnell,
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

The objective of this study was to investigate the effect of key extraction parameters of extraction time (5–25 min), acid concentration (0–0.06 M HCl) and ultrasound amplitude (22.8-114 μm) on yields of phlorotannins from A. nodosum. Response surface methodology was employed to optimize the extraction variables for phlorotannins’ yield. A second order polynomial model fitted well to the extraction experimental data with $R^2 > 0.79$. Extraction yields of 143.12 mg GAE/gdwb were obtained at optimized extraction conditions of extraction time (25 min), acid concentration (0.03 M HCl) and ultrasonic amplitude (114 μm). Mass spectroscopy analysis of extracts show that ultrasound enhances the extraction of high molecular weight phlorotannins from A. nodosum. This study demonstrates that ultrasound assisted extraction (UAE) can be employed to enhance extraction of bioactive compounds from seaweed.

Introduction

Seaweeds are a significant source of bioactive compounds with reported health benefits. Seaweeds are now being increasingly exploited as source of functional food ingredients and are also widely used in cosmetic and fertilizer products. Seaweed bioactive compounds include soluble polysaccharides, sulfated polysaccharides, carotenoids, omega-3 fatty acids, vitamins, tocopherols and phycocyanins (Kadam and Prabhasankar 2010). Phenolic compounds found in brown seaweed are known as phlorotannins which have many biological activities including antioxidant, angiotensin-I-converting enzyme (ACE-I) inhibition, bactericidal, and anticancer activity (Li et al. 2011).

Traditional methods employed for extracting bioactive compounds are time consuming and have low extraction efficiencies. To overcome these disadvantages, novel technologies for extraction of biologically active compounds from marine algae have been investigated including the use of enzymes, microwaves and super-critical fluids. Novel technologies and their applications for marine algal bioactive compounds are extensively reviewed in the literature (Kadam et al. 2013). Moreover, power ultrasound can also be used for extraction of bioactive compounds and has been reported for the extraction of bioactive compounds from natural sources including lycopene from tomatoes, anthocyanins from raspberries, phenolic compounds from citrus peel and coconut shell. Ultrasound has been demonstrated to be an economically feasible technology suitable for the extraction of thermolabile compounds. Ultrasound assisted extraction (UAE) is simpler and faster than microwave assisted extraction (Chandrapala et al. 2013).

The objectives of this study were to employ response surface methodology to (i) investigate the effect of extraction process variables (extraction time, acid concentration, ultrasonic amplitude) on yields of phlorotannins from A. nodosum and (ii) to optimize the extraction variables for bioactive compounds’ yield.
Materials and Methods

Seaweeds

Fresh brown seaweed (*A. nodosum*) was supplied by Arramara Teoranta, Co. Galway, Ireland. It was harvested, seaweed samples were washed thoroughly with fresh water to remove epiphytes and salt followed by oven drying using hot air at 40 °C for 12 hours. Dried seaweed was powdered using a hammer mill (Retsch SM100, GmbH, Germany) and sieved through a 0.5 mm mesh. Samples were stored at 4 °C prior to extraction studies for one week.

Ultrasound assisted extraction

Ultrasound studies were carried out using 4 g of A. nodosum powder placed in an extraction unit with 40 ml of solvent. The extraction process was carried out with a 750 W ultrasonic device (VC 750, Sonics and Materials Inc., Newtown, USA) at a constant frequency of 20 kHz. Ultrasonic power dissipation was calculated at each amplitude level, with temperature (T) recorded as a function of time (t) under adiabatic conditions using a T-type thermocouple. From temperature versus time data, the initial temperature rise dT/dt was determined by polynomial curve fitting. Extrinsic parameters of amplitude were 22.8, 68.4 and 114 µm which corresponded to ultrasound intensities of 7.00, 35.61 and 75.78 W cm$^{-2}$, respectively. Process variables of extraction time, acid concentration and amplitude level were used in this experiment.

Phlorotannins analysis and profiling using MALDI-TOF mass spectroscopy

Total phenolic content was determined using the method of Wang et al. (2013). Briefly an extract (0.5 ml) was mixed with 0.5 ml of diluted Folin–Ciocalteau reagent and 0.5 ml of sodium bicarbonate (7.5%, w/v) was added to the mixture. The absorbance was measured at 765 nm after storage for 60 min at room temperature. Results were expressed as mg gallic acid equivalent (GAE)/g dry sample.

The Molecular Weight Cut Off (MWCO) dialysis of extracts was carried out using Amicon Ultra-15 Centrifugal Filter Units with an MWCO of 3kDa. The extracts were dissolved in a minimal amount of deionized water and centrifuged for 6 hour at 4,000 rpm at 15 °C. Both the high molecular weight (HMW) retentate (>3 kDa) and low molecular weight (LMW) dialysate (<3 kDa) fractions were freeze-dried. Further fractionation of LMW fraction was carried out using a two-step reverse-phase (RP) flash chromatography method. RP flash chromatography was carried out with a Varian Intelliflash 310 flash system using a Reveleris C18 12g cartridge (Grace Davison) with a mean particle size of 40–60 µm. Freeze dried LMW fraction of 0.1 g weight was dissolved in minimum amount of distilled water and loaded onto the column. A two-step elution gradient was employed, whereby the mobile phases consisted of the primary eluent of water (0–10 min) and the secondary eluent of methanol (10–20 min). The flow rate was 40 ml/min. Flash fractions were collected from 0 to 10 min (flash fr.1), 10–20 min (flash fr.2). UV detection was observed at 210, 225 and 250 nm. Flash fraction 2 (from 10 to 20 min) was used for further analysis of phlorotannins.

Mass spectrometry analysis of the LMW polyphenol-enriched flash fr.2 samples was conducted using a Q-TOF Premier mass spectrometer (Waters Corporation, Micromass MS Technologies, Manchester, UK) by direct infusion into an electrospray ionisation source. Mass spectral data was obtained in the negative-ion mode for a mass range of m/z 100 to m/z 3000. Capillary voltage and cone voltage were set at 3 kV and 45 V, respectively. The desolvation gas was set at 800 l/h while the cone gas was set at 50 l/h. Samples were dissolved in methanol, filtered and infused at 10 µl/min for 2 min.
Results and Discussion

Total phenolics content of *A. nodosum* extracts varied from 63.54 to 139.73 mg GAE/g. A second order polynomial model fitted well to the experimental data with low standard error and regression co-efficient ($R^2$) value of 0.93 for total phenolics. The significance of all three experimental variables that affect the extraction process performance can be determined from the model coefficients, multiple determinations and probabilities generated from the RSREG procedure of SAS software.

Total Phenolics (mg GAE/g)

$$= 56.40 - 2.23X_1 - 525.75X_2 + 0.92X_3 - 12.36X_1 \cdot X_2 - 0.0008X_1 \cdot X_3 + 6.91X_2 \cdot X_3 - 0.008X_1^2 - 3204.17X_2^2 - 0.007X_3^2$$

![Figure 1](image)

**Figure 1:** Contour plots of total phenolics (mg GAE/gdb) of *A. nodosum* extracts as a function of (A) time to acid concentration (Amplitude = 68.4 μm); (B) amplitude to acid concentration (time = 15 min.); (C) amplitude to time (acid concentration = 0.03M)

The highest yields of total phenolics (139.73 mg GAE/gdb) was obtained using 0.03 M HCl at an ultrasound amplitude of 114 μm for an extraction time of 25 min. At higher acid concentrations, a significant decrease in extraction yields of total phenolics was observed (Figure 1). The decrease observed in extraction yield at higher acid concentration was probably due to acid hydrolysis and decomposition effects. A previous study has shown that the use of low acid concentration (1% of 12 M HCl) solvents for the extraction of grape anthocyanins led to partial hydrolysis of malvidin 3-O-acetylglucoside and important changes in the relative content of anthocyanins in grape extracts (Revilla et al. 1998). In this study an increase in phenolic content was observed with an increase in acid concentration for a ultrasonic amplitude of up to 68.4 μm. The use of water contributes to the creation of a moderate polar medium that facilitates the extraction of phenolic compounds (Liyana-Pathirana and Shahidi 2005).

Q-TOF-MS analysis indicates that ultrasound had no effect on degradation of phlorotannins. Although there are reports of alteration or degradation in the biological product due to use of high power ultrasound (Pingret et al. 2012, Pingret et al. 2013), authors in this study did not find any degrading effect. The sample with highest ultrasound power has yielded higher molecular weight phlorotannins. Also, comparison between mass spectra of extracts with acid and water, found that there was presence of additional higher molecular weight phlorotannins in extracts with acid as solvent for both ultrasound and control treatments. Thus, mild hydrochloric acid at conc. of 0.03M was found to be more suitable for extraction of phlorotannins.
Conclusions

In this study ultrasound assisted extraction was studied for the extraction of total phenolics, fucose and uronic acid from *A. nodosum*. Response surface methodology was employed to investigate the effect of process variables (extraction time, acid concentration, ultrasonic amplitude) to optimize the extraction variables for enhanced bioactive yields. Extraction yields of 143.12 mg GAE/gdb, 87.06 mg/gdb and 128.54 mg/gdb were obtained for total phenolics, fucose and uronic acid respectively at optimized extraction conditions of extraction time (25 min), acid concentration (0.03 M HCl) and ultrasonic amplitude (114 μm). Also, ultrasound has found to be efficient in extracting higher molecular weight phenolic compounds. This study demonstrates that UAE can be employed to enhance extraction of bioactive compounds from seaweed.

Acknowledgements

Authors acknowledge the financial support from Irish Research Council’s Embark Postgraduate Research Scholarship Scheme.

References


AN ENERGY AUDIT OF AGRICULTURE BUILDING IN UNIVERSITY COLLEGE DUBLIN TO REDUCE GREENHOUSE GAS EMISSIONS AND INCREASE SUSTAINABILITY

Veena Arulmozhi, Ger Devlin, Kevin McDonnell

UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Most electricity and heat requirements in the world are fulfilled by fossil fuel-based power plants. Inefficient and extensive use of energy has caused a strain on conventional energy resources worldwide. Evaluating the power consumption of energy equipment and other utilities of a building provides a good insight to the cost-effectiveness and energy efficiency of the equipment installed in the buildings. An energy audit of a commercial building summarises the details of history, its energy use bills, identifies the hot spots where energy use is maximum and suggests required improvements. Since buildings contribute to a major part of greenhouse gas emissions, governments in various countries have imposed strict laws for energy use. An energy audit is an initial step towards making a building energy efficient. This paper focuses on the energy audit of a commercial building, the Agriculture building based in the UCD campus.

Introduction

Pertaining to the fact that the majority of energy is derived out of fossil fuels, there is huge pressure on the fossil fuel reserves to meet the demand of the ever increasing population (Shafiee and Topal, 2009). The oil embargo in the year, 1973 saw a sudden increase in the oil prices and since then the fossil fuel prices have steadily increased (Hengeveld and Rodenburg, 1995). About 40% of the greenhouse gas emissions are from buildings (Krarti, 2000). The International Energy Agency (IEA) estimated that the energy efficiency policy introduced by the American Government has helped it in saving 50% of the energy consumed in the USA (Krarti, 2000). Nevertheless, the energy systems utilized in the buildings are not very efficient (Krarti, 2000). It is an official inspection of a building in order to measure the total energy consumption of the building and to suggest methods to reduce inefficient use of energy. The energy audit is carried out by qualified and certified professionals, and it takes into account the electricity, water and heat consumption of the building under consideration (Centre for renewable energy resource, 2000). The parts of the building which consume the maximum amount of energy are spotted and suitable measures to reduce the energy consumption are suggested. The energy audit is a step towards energy conservation, environmental protection and sustainable development (Building and Construction authority, 2010) (European Union Regulations, 2012). The energy audit can be either a walk-through audit or a detailed audit (Centre for renewable energy resource, 2000). In a walk-through audit, the previous year’s energy bills are examined by the energy auditor and a short survey of the building is taken. General housekeeping and other cost beneficial energy saving options are proposed to the occupants of the building under consideration. A detailed audit is an extensive process, in which the auditor acquires data and analyses it and suggests appropriate energy efficient and cost-effective measures (Electrical & Mechanical Services Department, 2007). A feasibility study is carried out and possible retrofit options are suggested. Retrofitting involves incorporating energy efficient technology in buildings, in order to reduce the dependency on the gas and electricity consumption and to improve general energy efficiency (Electrical & Mechanical Services Department, 2007).

The objective of this study is to conduct an energy audit on the Agriculture building in University College Dublin (UCD) and identify trends in energy usage together with hotspots of excessive energy use and to help reduce this energy consumption and associated greenhouse gas emissions.

Materials and methods

The Display Energy Certificate (DEC) of the agriculture building suggests it is categorized under D2 rated building according to the Building Energy Rating (BER) as the energy consumption of the building is 559kWh/m²/year. The ratings are perceived such that buildings which are rated A by the BER are very
energy efficient and have low carbon dioxide emission, and as the rating moves towards G, the efficiency reduces and the emissions increase (Sustainable Energy Authority Ireland, 2015). The energy efficiency of a building is calculated by

\[
\text{Energy efficiency} = \left( \frac{\text{energy input} - \text{amount of energy lost (OR) wasted}}{\text{energy input}} \right) \times 100.
\]

The building needs a proper audit, which can determine the energy efficiency of the building and suggest measures to improve the same.

**Figure 1:** Agriculture Building, University College Dublin (Google Earth)

An energy audit is planned for the Agriculture building of UCD; this building is categorized under large public domain buildings by the European Union (Sustainable Energy Authority Ireland, 2015). The steps involved to carry out the audit are shown in the flow chart below.

**Figure 2:** Flowchart describing energy audit methodology.

The energy audit needs to begin with understanding and analysis of energy consumption of the agriculture block. Hence, the electricity and heat consumption data were collected from the website by Cylon Active Energy for the past two years. The graphs below show the yearly, monthly and weekly curves for the year 2014. It is observed that electricity consumed in the month of July is 123,114kWh, that being the maximum consumption of the year; this is perhaps strange given that it is the summer term with no undergraduate students. However, this is just one issue that the analysis will solve.

The heat consumption of the building varied according to the seasonal changes. The seasonal loads are the heating and cooling system in the building and loads like the lighting, ventilation and other equipment are categorized under baseline loads.

A list of questions is prepared which will be asked during the walk-through audit, to the room allocations and building services. These departments could help in knowing the duration for which the classrooms are used and information related to the heating system adopted by the building. The survey would help in identifying any unnecessary use of power happening in the building. The information on operation and maintenance practices of the equipment in the building can also be secured. After the walk-through audit, a simple narrative about the building’s architecture, age, occupancy and electrical and mechanical system characteristics will be prepared (Reyes et al., 2006).
The next step would be suggesting a few amendments to the daily use of power, apart from making it mandatory to switch off power supply when the equipment is not in use. Other measures include installing better-rated equipment and reducing the time of operation, without disturbing the smooth functioning of the building.

*Calculation of demand*

The next important thing is to calculate the energy demand of the building. It is easier to calculate the lighting load demand as it depends on the working schedule and the installed power of the lighting equipment. However, the demand of air conditioners is difficult to calculate as it varies according to the temperature and humidity set point (European Union Regulations, 2012). Various simulation models are available to calculate the energy demand of the buildings, like EnergyPlus, TRNSYS, etc. and it may be possible to incorporate some of these tools.

*Calculation of load factor*

The study of load factor relates energy demand (in kW) to the energy use (in kWh). Load factor calculations help to determine suitable changes in the operating hours of energy intensive loads.

Load factor = Energy use / number of hours in the billing period

This helps in determining the cost saving potential by shifting some loads to the off-peak hours to reduce peak demand (Reyes et al., 2006).

A detailed analysis will be carried out and suitable changes in the operation of the heavy load equipment will be suggested. There are few renewable energy retrofit options available for large public sector buildings, like fitting solar PV panels on rooftops, combined heat and power (CHP) or harnessing geothermal energy. However, these retrofit options, demand renovation of the building, which might not be feasible in this case.

**Figure 3:** Graphs of electricity consumption for the year 2014 (Cylon Active Energy)
Results and discussion

The energy audit will summarise all the information related to the building’s architecture, occupancy details, equipment installed, power demand, load factor and simulation results. Any power loss happening inside the building will also be reported, suggesting a suitable and economically viable alternative. The walk-through audit and the calculations related to the power rating of the equipment, and the actual demand of the building will also be carried out. If the calculations tally and the power consumption of the building is justified, then ways to improve the energy efficiency of the building would be suggested. There can be two scenarios which could possibly be the outcome of the audit. Either there could be an unidentified power loss, inside the agriculture building which would be revealed during the audit, or the poor rating of the equipment used in laboratories, lighting heating/cooling systems or ventilation might be the cause of high energy bills. The results are yet to be obtained when the audit is carried out.

Conclusion

The energy audit will reveal all the information pertaining to the operation and maintenance of the equipment present in the agriculture building. It will help in identifying hot spots and possibly help to move the high power consumption equipment usage to off-peak hours if convenient. The audit will suggest sustainable and suitable energy conserving alternatives, resulting in reduced energy bills. This audit could prove useful to increase the BER rating of the building and help reduce the carbon emissions.

Acknowledgments

The audit will be carried out with the consent of the Head of School of Agriculture and Food Science Prof Alex Evans. Sincere thanks to the room allocation services and the building services of UCD. The authors would also like to acknowledge Cylon Active Energy, Ireland for their contribution to the study by providing the energy consumption data.

References:


ASSESSING THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON THE WIND ENERGY RESOURCE OF IRELAND

Bernadette Convery and Patrick Grace
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract
Wind energy has become increasingly popular in Ireland, with this trend expected to continue well into the future due to the island’s exceptional wind energy resource and will contribute significantly in enabling Ireland to meet the 2020 national target for electricity production from renewable resources and indeed any further targets throughout the century. This study investigates the potential of climate change in altering the wind patterns in Ireland and hindering the ability of wind energy to meet its future expectations.

Introduction
Due to the increased combustion of fossil fuels for energy generation since the beginning of the Industrial Revolution, anthropogenic forcing has contributed significantly to climate change through increased greenhouse gas (GHG) emissions. Resource depletion of non-renewable fossil fuels has become a significant issue as overconsumption threatens the reserves for future generations, therefore the demand for more renewable energy sources is essential for the mitigation of these harmful greenhouse gases and for a stable energy resource. In 2010, 86% of fossil fuels consumed in Ireland were imported (Goodbody et al., 2013) hence high dependency on exporting countries. In relation to Ireland, the increase of energy production from renewable energy sources will ensure a much more secure indigenous energy supply, decrease the high dependency rates and contribute to reaching national targets of 40% of the islands electricity from renewable energy by 2020 and Kyoto Protocol targets of a reduction in greenhouse gas emissions by 2020 to be 20% below 1990 levels and by 2050 to be 80-95% of 1990 levels.

Of all the renewable energy resources, wind energy is expected to contribute to the majority of the renewable energy production and decarbonisation strategy as Ireland has an exceptional estimated technical resource of ~613 TWh/ year, with wind energy alone displacing approximately 1.28 million metric tonnes of C02 emissions in 2009 (O’Rourke et al., 2009). In 2014, the installed wind capacity on the island of Ireland was ~2,889 MW and it is expected that in order for Ireland to achieve the 2020 target of 40% electricity from renewables that 5,500-6000 MW of wind generation is required (SEAI, 2012) and therefore an increased investment and reliance on wind energy. There are many benefits associated with the utilisation of Ireland’s wind energy potential, with one of the main advantages related to curtailing the impacts of climate change through electricity production from a carbon neutral fuel. However as wind energy is driven by the climate it is therefore potentially susceptible to exposure and alteration as the energy balance of the earth changes with an altering climate. Currently, the intermittent nature of the wind coupled with potential future alteration of the wind regime, such as changes in wind speed, may have a negative impact on the resource as current technology is designed to operate at present conditions.

The objective of this study is to assess the potential impacts of climate change on renewable energy resources and technologies, specifically wind energy in an Irish context.
Materials and Methods

This paper will examine the potential of climate change in altering the future wind patterns in Ireland, as currently wind energy is the most highly utilised renewable resource in the country and is set to increase installed capacity if Ireland is to reach the 2020 target of 40% electricity from renewables and increase scale on the global energy market through future exports of surplus energy through an interconnector to Great Britain, this would require a capacity of over 10 GW by 2050 as presented in figure one which portrays Ireland’s potential to meet electricity demand from wind energy by 2030 and the surplus potential for export by 2050 (SEAI, 2013). However increased reliance upon wind within the Irish energy sector for future economic and energy stability may be hindered by a change in the wind climate and the question arises as to whether so much effort should be focused around this particular renewable resource or whether Ireland should look towards a larger contribution from other renewables.

Figure 1: Wind energy roadmap 2010-2050 (SEAI, 2013)

The intermittent nature of wind alongside the uneconomical storage potential are the main disadvantages associated with the resource, making it hard to predict in terms of energy supply hence an uncertainty related to integrating higher levels of wind in the Irish system with the maximum current contribution of 50% electricity demand in Ireland in order to maintain system security. A changing climate has the potential to increase the unpredictability of the wind regime and destabilise the energy resource further. Any change may have a negative effect upon the current installed wind turbines in Ireland which operate best at the current mean annual wind speeds at 50 m. An increase in storm events or high wind speeds would result in an increase in stalling periods of the turbines, a decrease in wind speed would result in increased fatigue periods, a change in air density related to increasing air temperatures would lead to a decline in air density hence a slight decline in power production (Pryor and Barthelmie, 2010). These are the negative impacts associated with a change in wind regime; there are however potential positive impacts such as an increase in mean wind speed leading to greater potential power supply.

The scenarios of future climate change through to 2100, as projected by the IPCC (2007) will be used throughout this project to assess the impact of increased greenhouse gas emissions on the global climate system with a projected warming trend in the temperature of approximately 0.2 °C per decade and investigate whether these scenarios will have any influence, hence change on wind climatology for Ireland. The results of various Regional Climate Models carried out in previous studies (Nolan et al., 2011; Pryor et al., 2005) will also be compared and analysed in relation to a changing wind
climate in order to identify potential impacts upon current installed wind turbine technologies and energy production.

Different scenarios relating to those outlined in the IPCC 2007 report for future climate change scenarios alongside current and projected future wind turbine properties will be calculated using the equation:

\[ W = \frac{1}{2} pAV^3 \]

Where:
- \( W \) is power
- \( p \) is air density
- \( A \) is the rotor area \((\pi d^2/4)\)
- \( V \) is the wind speed

These calculations will allow for comparison of scenarios under which changes in air density, wind speed (related to climate change) and technology characteristics will affect the theoretical amount power available in the wind in the future for certain types of design.

Although there are current issues with the economic aspect of back up storage in relation to wind energy in Ireland, future potential opportunities such as the Gaelectric project of Compressed Air Energy Storage (CAES) in Larne, Northern Ireland, where a storage cavern in a geological salt deposit may have the potential to store some of the excess energy from wind production therefore limiting the curtailment of future wind energy in Ireland (Gaelectric, 2012), will also be considered in the evaluation of dependency on the future wind resource.

Results and Discussion

The results of the calculations to be carried out will be analysed under the different climate change scenarios, the expected results of the calculations are a general increase in energy production with increased wind speeds but also an increase of stalled periods related to turbine design. An increase in stalling in the turbines would be a negative problem associated with the continuity of supply and therefore a possible need for a change in turbine design to adapt to such instances. For increases in air density the results are expected to show a decline in the output of the resource, for a slight increase in the wind speed there would be a positive impact on energy generation given that energy in the wind is the cube of wind speed, hence a higher output. Frequency curves with power output as a function of wind speed will be created for each of the scenarios and compared to identify what the worst case scenario will be in terms of power outputs, this has been successfully achieved in previous studies (Pryor et al., 2005).

The idea of emerging energy storage such as the Gaelectric project will be assessed alongside the results from the different wind pattern alterations for Ireland and compared to other similar storage systems utilised for the same purpose in other countries.

Conclusion

Wind energy is the most relied upon renewable resource for electricity generation in Ireland with the benefits of no emissions associated and a secure indigenous supply reducing dependence on imports of fossil fuels hence complimenting the economy, this reliance and capacity is set to increase in the future to enable national and European targets to be met. However the impacts of climate change on the wind resource are often not considered and could prove to be a significant problem for renewable energy production if Ireland focuses the majority of generation from wind energy. This study is expected to show that climate change will slightly alter the potential of wind energy production with increased stalling associated with more extreme storms during winter and a decrease in summer
months leading to a very unreliable energy resource, however the potential of new forms of energy storage are expected to offset the unpredictable nature coupled with interconnectors hence allow for a higher contribution of wind energy in the Irish system.

References


A FEASIBILITY STUDY OF POWERING ADJACENT COMMUNITIES FROM DECENTRALISED RENEWABLE ENERGY HUBS IN KAZAKHSTAN

Muhtar Koshkarbayev and Kevin McDonnell
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Municipal solid wastes (MSW) disposal and treatment is a great challenge for municipal officials in many developing countries due to the environmental issues like possible air, soil, and water pollution; land use and aesthetics; and odor nuisance problems. However, reasonable and efficient utilization of MSW can solve the environmental problems as well as can be an additional source of renewable energy and recycled materials. This paper investigates the feasibility of building and operating a decentralized “green” energy hub on the basis of MSW landfills in Kazakhstan which harvests solar, wind and energy from waste to generate electricity for the adjacent communities.

Introduction

Development and versatile support of Renewable and Green Energy, Energy Efficiency strategies which are adopted by the Republic of Kazakhstan (RoK) are mainly aimed to reduce GHG emissions and preserve the fossil fuels for the next generations. The government of the Republic of Kazakhstan widely promotes and advocates research and projects which facilitate elaboration, application and employment of renewable and clean energy in real sector of Kazakhstan’s economy. According to Accounting and Finance Center (RFC) to support renewable sources of energy, Kazakhstan Electricity Grid Operating Company (KEGOC) is purchasing electricity from renewable energy producers in the range from 21 euro cents (46.6kzt) to 27 euro cents (58.6kzt) per kWh depending on the technology deployed. The comparison of the purchasing prices as of 14/02/2015 between RoK and Ireland, EU market member, where Renewable Energy Feed in Tariff (REFIT) varies from 8 euro cents to 15 euro cents per kWh also depending on the technology deployed makes Kazakhstan’s renewable energy market more attractive for business projects.

In order to make the project and the produced energy really green and sustainable the project activities, equipment & material procurement and supply chain will be screened through Life Cycle Assessment concept and approach.

Atyrau city, Kazakhstan was chosen as a case study in this paper. Atyrau is typical city, situated in the western part of Kazakhstan with the Ural River which flows through the city into the Northern part of the Caspian Sea. The population of the city as per national statistical data of 2013 is 265,200 people.

The objective of this study was to evaluate the technical feasibility of combining the renewable energy technologies which can be implemented at MSW landfill and convert indigenous and locally available solar, wind energy and energy contained in MSW to meet power demand of 100 householders from the established decentralized energy production system.
Review of Technology Design and Operation

Overview of renewable energy resources potential in Atyrau region

**Wind:** Atyrau region is very suitable to wind energy applications due its proximity to the Caspian Sea. Through the project “Kazakhstan-Wind Power Market Development Initiative” supported and sponsored by both UNDP/GEF and government of Kazakhstan, the wind resources of RoK were thoroughly assessed and the wind atlas (see figure 1) with the precise and accurate data for certain locations is available now online at www.windenergy.kz for public use and benefit.

![Wind atlas of Atyrau](image1)

**Figure 1.** Wind atlas of the site in Atyrau at height of 80 m above ground level (available at www.windenergy.kz)

According to the published data (available at www.windenergy.kz) of the assessed sites, Atyrau site has an assessed potential wind capacity of 100 MW with the wind average speed 6.8 m/s at height of 50 m above ground level.

**Solar:** Kazakhstan has areas with high insolation that could be suitable for solar power, particularly in the south of the country, receiving between 2200 and 3000 hours of sunlight per year, which equals 1300-1800 kW/m² annually. Both concentrated solar thermal and solar photovoltaic (PV) have potential” reported by M. Karatayev and M. Clarke (2014) in their review. As shown on the figure 2, Atyrau region has an excellent solar energy production potential with its 1450kWh/m².

![Solar irradiation map](image2)

**Figure 2.** Solar irradiation map of Kazakhstan (available at www.solargis.info)

**MSW:** As there was no available scientific data on energy content of MSW in Atyrau, the lead author of this paper conducted a personal survey on physical composition of MSW in
Atyrau in January, 2015. Two waste containers from different municipal waste collection points were physically examined; the waste was segregated by type and weighed. The obtained results enabled the calculation of the energy content of MSW given that Atyrau disposed 60 tonnes of MSW daily in accordance with statistical data for 2013. The approximate value of MSW energy content was determined using Khan’s equation (Khan et al. 1991):

\[ \text{Eh} = 0.051 [F + 3.6(\text{CP})] + 0.35(\text{PLR}) \]

The energy content of 60 tonnes of MSW was estimated as 179 MWh or 647 GJ.

![Figure 3. MSW composition by weight and type.](image)

**Overview of renewable energy technologies**

To meet the project concept which is being marketed as a green and sustainable one, all technologies and the associated equipment and material available in the market should be locally produced or with minimal environmental burden through the life cycle which can be confirmed by Life Cycle Assessment (LCA) study or Environmental Product Declaration (EPD).

Solar energy could be harvested and converted to useful energy in many ways; the most reliable, mature and commercially available are solar thermal, solar photovoltaics and concentrated solar power technologies. The choice of the solar technology that will be used in the project is predetermined by the fact that Kazakhstan locally produces poly-crystalline silicon photovoltaics panels using Kazakhstani silicon raw material. Another factor mentioned by L.Chaar et al (2011) also counts in favour of poly-crystalline PV panels is the beneficial cost-efficiency ratio comparing to mono-crystalline and thin-film panels. Poly-crystalline panels are less expensive to produce than mono-crystalline ones but more expensive than thin-film panels. They are more efficient than thin-film ones but slightly less efficient that mono–crystalline panels.

Wind energy is suggested to be harvested by an industrial sized wind turbine with horizontal axis and three blades and presumably made by a well-known EU manufacturer. It is expected to use a turbine tower height of 80 m with power capacity of 1.6MW.

Gasification as MSW thermal treatment technology is under consideration for this project. The choice is driven by the fact that gasification offers the possibility to produce fuel i.e. syngas, which can be stored and used later when additional electrical power production is required.

**Sizing the energy production system**

An approximate inventory of a typical Atyrau’s household electrical energy consumption revealed that possible peak power demand during the day is 12 kW. Consequently the peak power need of 100 households is 1.2 MW. However for contingency purposes, possible capacity expansion needs in the future and for internal needs of the energy production system...
an additional 50% was added to this figure, which resulted in 1.8 MW system for the whole project. Thus an energy production system should have a power capacity to generate 1.8 MW for the project. The word “project” is used here in the context of electrification of 100 households by means of renewable energy systems as well as for the internal needs.

**Results and Discussion**

The primary energy sources for electricity production would be solar PV panels with power production capacity of 1 MW at minimal sunshine period and two wind turbines with power production capacity of 1.6 MW (each) for the rest of the day, where and when the peak load is forecasted not to be met, the stored syngas would be utilized to produce electricity to cover the expected power shortages. This redundancy approach in renewable power production system is expected to make the system self-sufficient and a reliable source of electricity from the decentralized supplier.

**Conclusions**

The proposed model of building the decentralised energy production and supply system on the basis of landfill diversion brings many advantages like:

- Diverts MSW from landfilling to thermal treatment with energy recovery.
- Promotes the best practices application in line with Waste Treatment Hierarchy
- Reduces GHG emissions, soil and ground water pollution from landfill
- Supplies clean and renewable energy from decentralised system

**References**


PULSED ELECTRIC FIELD PRETREATMENT OF ANAEROBIC DIGESTION FEEDSTOCK TO INCREASE BIOGAS YIELD

Anant Kumar and Kevin McDonnell
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Ireland is lagging in meeting the EU directive for renewable energy uses for heating and transportation. Anaerobic Digestion (AD) has the potential to fill this void. In the biogas up-gradation process, methane content is increased from the usual 50-75% to 95%. Biogas with 95% methane content can be directly used for heating purposes and as compressed natural gas in transport. It is more reliable than any other renewable source of energy like solar, wind, etc. Also, it is carbon neutral. AD provides a better utilization of biomass and organic biomass produced by AD can be used directly by Irish farmers. However, higher hydraulic retention time (HRT), lower methane content in the biogas (50% to 75%) and lower biogas yield are a few of these challenges faced by the biogas industry. These problems can make the anaerobic digestion business non-profitable and unattractive. This study aims to investigate the application of pulsed electric field pretreatment on feedstock materials, improvement in the yield of biogas, HRT reduction, and increase in biogas methane content.

Introduction

Anaerobic digestion is a multi-step process in which bacteria break down complex organic matter into simpler compounds (like methane, carbon dioxide, ammonia, hydrogen sulphide, etc.) in the absence of oxygen. The steps in AD include hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Hydrolysis is the rate-limiting step. It determines the overall performance of anaerobic digestion. In hydrolysis, complex organic materials (starch, cellulose, fatty acids, and proteins) break down into smaller compounds (glucose, sugar, and amino acids) which are used by the acidogenesis, acetogenesis bacteria. Inefficient hydrolysis reduces the amount of volatile organic matter available to bacteria in the next stage. This leads to a reduction in the biogas production and an increase in the solid HRT (Nizami et al. 2009, Ariunbaatar et al. 2014). Several pretreatment methods have been applied to improve the efficiency of anaerobic digestion. Pretreatment methods either try to reduce the HRT or increase biogas yield in the AD. Some of these pretreatment methods are thermal, chemical (alkali or acid), UV radiation, or mechanical (Ariunbaatar et al. 2014). This study tests the applicability of pulsed electric field (PEF) for the pretreatment of feedstock. PEF has been successfully used in food and beverage industry to destroy the cell walls of fruits and vegetables for extraction and to introduce molecules into cells through temporary pores in biotechnology (Cserhalmi et al. 2006, Toepfl et al. 2007). In PEF, short, intense electric impulses are applied on the biomass, which opens the pore in the periplasmic membrane and peptidoglycan layer (Rittmann et al. 2008, Salerno et al. 2009, Zhang et al. 2009). The pores are held open for long enough time, which results in the release of cellular material outside the cell. It creates osmotic shock that results in the lysis of the cell wall. The cell wall breakdown improves the amount of volatile organic matter available to use for bacteria that result in the improvement of biogas production and HRT reduction. Water is used as electrical conduit material to conduct impulses through the material (Bouzrara and Vorobiev 2003, Rittmann et al. 2008, Salerno et al. 2009)

The objective of this study is to investigate the application of pulsed electric field treatment on anaerobic digestion feedstock to increase the biogas production and retention time reduction.
Materials and Equipment used

The lead author has taken a site tour to the AD facility by Green Generation in Co Kildare. It is a two-stage thermophilic anaerobic digestion. The biogas produced from the AD plant will be supplied to the gas grid after on site biogas up-gradation. Feedstock available for use on site includes belly grass, milk sludge, grease trap fat, cow manure, pizza waste, horse stable bedding and pig manure. It is the first plant in the Republic of Ireland which will operate in a thermophilic condition using mixed feedstock. Easy access to the plant to the Green Generation AD and verification of the lab scale results are the main reasons for working in close collaboration with the company. Dry matter content, moisture content, ash content, and energy content of all these feedstock will be estimated by oven drying and bomb calorimetry prior to pulsed electric field treatment and AD. The materials and equipment used in this study are two litre flask, gas analyzer, thermometers, pilot-scale PEF system (ELCRACK HVP-5, DIL), pH meter and feedstock (Carlsson et al. 2008, Salerno et al. 2009, Lindmark et al. 2014). The feedstock will be kept in a sealed glass flask to initiate anaerobic digestion as shown in Figure 2. The biogas formation rate and methane content present in the biogas will be estimated by taking the readings of flow rate, temperature, pH, and biogas sample on a daily basis.

Sample Preparation

Stone and other unwanted materials will be removed. Belly grass, pizza waste, and straw will be cut in uniform size to ensure homogeneity. PEF treatment will be performed using a pilot-scale PEF system (ELCRACK HVP-5). After pretreatment, feedstock will be treated in AD at both mesophilic and thermophilic temperature: 1. Control sample, 2. Individual feedstock and 3. Mixed feedstock.

Pulsed Electric Field Treatment

The parameters like output voltage, pulse width, pulse frequency, pulse number, treatment time and energy emitted will be varied in order to determine the impact of pretreatment analysis and better interpretation of the result. The energy released at each pulse is calculated as

\[ E = 0.5 \times C \times U^2 \]  

(Where, C and U are the capacitance and the loading charge respectively (Carlsson et al. 2008)

![Figure 1. Schematic diagram of pulsed electric field treatment (Anon 2012).](image)

The samples will be kept in the sealed two litres flask available in the lab. The medium will be sparged with N\(_2\) to remove any oxygen in the flask. Sealed condition of the flask will keep the anaerobic condition. Digested slurry (semi-solid material which contains anaerobic bacteria) procured from the operational anaerobic digester plant will be used as inoculum. It will initiate the production of anaerobic bacteria in the flask. The anaerobic digestion in the flask will start producing biogas from the second
week. The production of the gas will increase with time till the sufficient feedstock available for the bacteria. A thermometer will be inserted into the container to take the temperature readings and tubes will be used to take biogas samples as shown in Figure 2.

![Figure 2. Anaerobic digestion batch bioreactor for biogas analysis (Kavuma 2013).](image)

**Gas Collection & Analysis**

The biogas analyzer will estimate the content of biogas (CH₄, CO₂, CO, H₂S) produced from the anaerobic digesters. The gas analyzer can measure any minute changes in the flow rate and concentration of the gas due to its high sensitivity. The biogas will be collected in a sealed bottle or plastic bag. Data generated by the gas analyzer will be further verified by the water displacement method by estimating the amount of water displaced by the biogas. The methane content will be estimated by injecting the gas in a closed gas/liquid separator containing alkaline solution (e.g. 3% NaOH). The CO₂ will be "trapped" in the liquid (it will react with NaOH) and the CH₄ will pass freely through the solution. The quantity of the collected gas will give the content of CH₄.

**Expected Result**

As experiments are ongoing, it is possible to speculate on the result based on previous studies. The feedstock suitable for PEF treatment shall be identified. It will also help in the identification of optimum voltage and pulse requirement for different feedstock. Previous studies have shown that electroporation can enhance the methane yield from organic waste. There is 2-8% increase in yield with respect to energy as has been reported in the previous studies (Bouzrara and Vorobiev 2003, Rittmann *et al.* 2008, Salerno *et al.* 2009, Zhang *et al.* 2009). Also, the operational large-scale anaerobic digester will be checked to validate the result of the lab scale experiment.

**Conclusions**

This study aims to examine the pulsed electric field pretreatment and suitable feedstock for a large scale thermophilic anaerobic digestion plant. An increase in methane volume or decrease in retention time without any reduction in the biogas volume will support the effectiveness of pulsed electric field. Since, higher content of degradable organic material is made available by the pulsed electric field pretreatment, is used by the anaerobic bacteria to produce higher volume of methane and biogas.
Bench scale anaerobic digestion treatment will help in the selection of the best combination of the feedstock for the large scale uses in the anaerobic digestion for higher concentration of methane gas and also higher output of biogas.

References


THE TECHNICAL AND ECONOMIC FEASIBILITY OF SITING A PILOT SCALE ANAEROBIC DIGESTER AT UCD

UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

The major research institutions in Ireland have a key role to play in the modernisation of the country’s infrastructure. Piloting an innovative, renewable energy technology such as an anaerobic digester at UCD can have a combined effect of determining the feasibility of the technology whilst simultaneously providing a template for prospective commercial stakeholders to assess. A technical and economic feasibility study will be carried out on the technology with the aim of evaluating the feasibility of small-scale anaerobic digesters for Irish market penetration.

Introduction

The fact that Ireland has a high reliance on foreign fossil fuels, an archaic waste management system and poor compliance with EU renewable energy targets is almost an exhaustive statement at this point in time. While the reasons for adopting modern, renewable energy technologies are unequivocal, the incentives for doing so are less pronounced in Irish consumer, commercial and industrial sectors.

Among the many renewable energy systems (RES) Ireland has yet to adopt, anaerobic digestion appears to be particularly applicable to the Irish context at least on a technical level. The key selling point of this technology is that it utilizes local wastes as a resource to generate local energy, offsetting fossil fuel usage whilst minimizing pollution and greenhouse gas emissions (Asam et al 2011). Alternatively, the technology can utilize purpose grown energy crops which are considered “carbon neutral” as any associated emissions with the process (harvesting cultivation etc.) are sequestered by the crop itself during its growing phase (Knitter 2013).

Anaerobic digestion is the decomposition of complex organic matter within an oxygen-free environment. The process itself involves three main stages; hydrolysis, acetogenesis and methanogenesis which are all inter-related but which require differing environmental conditions, optimisation of which is crucial to ensure maximum methane output (SEAI 2011). In designing a biogas plant, the main aim is to maximise biogas potential whilst minimizing water content of the substrates and ensuring high loading rates in order to ensure financial optimisation (Asam et al., 2011).

Wall et al (2013) estimates that the construction of 170 digesters, co-digesting a feedstock of grass silage and dairy slurry would generate ca. 10% of Ireland’s renewable energy supply in transport. Despite an abundance of potential, the Irish markets have yet to embrace this technology for a number of reasons. Gaining planning permission can prove tedious and there are a number of licences which must be sought before building a digester (SEAI 2014). In addition, digesters are built on a bespoke basis depending on the type of feedstock available in any given scenario, prompting uncertainties within prospective stakeholders relating to capital costs and payback periods.

Ireland’s major research institutions can play a major role in pushing anaerobic digestion into the Irish markets. UCD in particular is in a prime position to pilot such a project with such a vast requirement for energy on the demand side whilst possessing sufficient resources to cope with the initial capital cost. Once complete, a prospective project could be used for research purposes, providing academics with a facility to practice different techniques with a view to optimising the technology.

The objective of this study is to determine the technical and economic feasibility of siting a pilot-scale anaerobic digester at one of the facilities owned and administered by UCD.
Materials and Methods

Reactor design
As mentioned previously, reactors are generally designed to suit the predominant feedstock type. However, there are three main types which this study will consider; single phase, two-stage and sequencing batch reactors. Single phase reactors, despite being the least efficient at producing biogas, are the most commonly utilized type for commercial biogas plants (Azbar et al 2001). Two-stage digester configurations consist of two reactors in sync with one another. This allows for the optimization of one reactor for hydrolytic and acetogenic conditions while the other can be adjusted to suit methanogenic micro-organisms, leading to a greater biomethane potential (Nizami et al 2009). The final system considered, a sequencing batch leach bed reactor was found to produce the most biomethane however was found to be least sustainable with regards to emissions savings and parasitic energy demands (Singh et al 2011). Also to be taken into consideration, are types of pre-treatment methods such as maceration in order to homogenize particle sizes, giving a greater surface area for the microbes to act upon (Asam et al 2011). Selection of an appropriate technology for the biogas plant at UCD will be made pending the other results of this study such as cost and substrate type.

Substrate type
There are many varieties of substrates which can be readily utilized by anaerobic digestion however proximity to the biogas plant is usually the key factor in selecting a feedstock as to minimize transport costs. Wall et al (2013) notes that Ireland’s most ubiquitous substrate source is grass and demonstrates that co-digestion of such with dairy slurries achieve substantial yields of biomethane. Ensilage of grass can raise its dry solids content resulting in a higher yield of biomethane compared to fresh cut grass (Nizami et al 2009). Other avenues UCD could pursue in securing feedstocks for the digester is the utilisation of the organic fraction of municipal solid waste (OFMSW). Mata-Alvarez et al (2000) have shown that this type of feedstock is readily available on the supply side however considerable pre-treatment and thermophilic conditions are required to optimize biogas production leading to high parasitic energy demands. Selecting the right feedstock for UCD will primarily involve a survey to determine what types of feedstocks are available followed by an investigation into what type of reactor is appropriate for this feedstock.

Cost and payback period
Upon selecting a reactor design it will be necessary to ascertain the associated costs of building the entire system as precisely as possible. At this point it is useful to envisage the project as a biogas plant as opposed to an anaerobic digester as not to overlook any hidden costs. By liaising with engineering firms and the UCD Buildings and Services Department; the capital cost for the digester, mixers, pumps, silos, heaters and pipes will be assigned a value. To estimate operating costs and payback periods, Anderson et al (2013) suggests the use of a financial tool they devised for determining the feasibility of anaerobic digesters by the assignment of an applied net present value (ANPV). Another massive potential cost is the construction of a co-generation unit which is entirely necessary if the excess heat generated is to be utilized efficiently.

Legislation
There are a number of regulations and permits which must be obtained before the commencement of a biogas project such as planning permission, waste permits, disinfection permits and animal by-product regulations (SEAI 2011). Planning permission may be sought from the Dun Laoghaire-Rathdown County Council. Disinfection and waste permits shall be attained from the EPA while it is necessary to apply to the Department of Agriculture Food and the Marine for an animal by-products licence. A considerable amount of time will be spent deciphering the legislation and liaising with the respective governing bodies to establish the precise criteria of standards an on-campus digester must meet as well as an accurate timeline in which these permits can be granted.
Results and Discussion

As this project is still underway it is anticipated one of the following scenarios will present itself as the most feasible option in siting an anaerobic digester at UCD:

Scenario 1: Siting an anaerobic digester on the UCD campus
A massive cost-saving aspect of this scenario is the pre-existence of a cogeneration unit on campus, provided the system can be adjusted to allow a biogas facility to connect to it. In addition the UCD campus uses approximately 100GWh annually hence even in times of low demand, a grid connection is probably unnecessary, saving further on capital costs (UCD 2015). In 2013/14 UCD spent €7.5 million on energy use thus the return on the investment can be calculated on the savings made from offsetting use of conventional fossil fuels. SEAI (2011) highlight the fact that during their operation, anaerobic digesters must be supervised at all times and frequently require maintenance to ensure optimum performance. The UCD energy unit should be more than competent in assuming these roles hence a further saving can be made on running costs. The highest uncertainty to the feasibility of this scenario is the sourcing of a steady and energy-rich feedstock with minimal transportation costs. At this early stage in the project it is difficult to identify applicable feedstocks with more than a speculative estimate. Consideration would also have to be given to nearby residences or other groups who may object to having a biogas reactor near their properties.

Scenario 2: Siting an anaerobic digester at Lyons Farm
The production of agricultural residues from crops; along with the collection of animal slurries are likely to be of sufficient quantities to justify the construction of a pilot-scale digester at this facility. While the use of local feedstocks would significantly reduce transport costs, there is an issue with the demand side of this scenario, with an uncertainty over what facilities could avail of the excess power generated. In addition a cogeneration unit would have to be constructed here in conjunction with a grid connection to allow the sale of the excess electricity hence driving up the capital costs.

Scenario 3: Worst case scenario
The financial estimates from the ANPV model suggested by Anderson et al (2013) prove too costly and a lengthy payback period inhibits the development of a biogas unit at either facility. There could be some merit in operating the facility at a minor loss for the sake of experimental and research purposes, with a view to optimizing future AD practices in an Irish context. However it is highly undesirable to have a technology which leaks money as this weakens its credibility as a template for prospective stakeholders to work from.

Conclusions

Anaerobic digestion is a relatively mature technology in widespread use throughout Europe. It is highly likely that it is suited to an Irish context resulting in the validation of one or both of scenarios one and two and the rejection of scenario three. It is anticipated that a significant proportion of the ambiguity associated with the technology of AD itself, its cost and the accompanying legislation; will become more transparent from the results of this study.

Acknowledgements

The authors of this paper would like to thank John O’Halloran of the UCD School of Chemical and Bioprocess Engineering for the invaluable advice on the various processes of anaerobic digestion along with its context in Ireland. The authors are also grateful to Tom Canning of ESB International for the information provided on grid connections and co-generators.
References


AN ASSESSMENT OF THE PUBLIC PERCEPTION OF HYDRAULIC FRACTURING IN IRELAND THROUGH QUANTITATIVE RESEARCH

Megan Nolan and Enda Cummins
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Hydraulic fracking has generated a large amount of energy and controversy in recent years across the globe and in particular in the USA. America is used as a success story to justify the positives of the technology in terms of energy security and economics. This unconventional method to extract shale gas has recently become a focus point in Ireland. The object of this study is to examine the public perception of fracking and test the hypothesis of whether there is an overriding negative public perception of fracking in Ireland. The survey will include knowledge of the technology, level of support/opposition and awareness of potential impacts. Two case study areas will be surveyed in County Fermanagh and County Westmeath with the results being analysed using appropriate statistical tools taking into consideration the limitations of the approach adopted. The research will aim to assess Irish people’s views on hydraulic fracking in Ireland and identify the reason behind such views.

Introduction

The development of hydraulic fracking has brought about a lot of controversy. The drilling companies argue with the public that fracking will accelerate economic growth and help countries to become less reliant on imported fuels (Perry et al., 2012) while the public focuses on the impact the technology has on their communities. Understanding the public perception of fracking is important for governments and the competent authorities involved because it is a measuring tool on how the nation feels about the technology. The benefit of opinion surveys is that they offer insight into people’s level of support or opposition as well as overall perception.

Hydraulic fracturing is commonly called “fracking” as the technology fractures the rock in order to release the unconventional gas reserve (Armstrong et al., 1995). The fracturing of rock is created by high volumes of water mixed with chemicals and incompressible particles such as sand through a wellbore. The incompressible particles hold open the fractures in the rock and the gas flows to the well (Pallisner et al., 2012). Hydraulic fracturing requires 2–10 million gallons of water per well per fracture (Soeder and Kappel, 2009), which raises concerns about depletion of surface or ground water sources. Social impacts associated with energy development booms are also of great concern to communities in close proximity to fracking sites (Brasier et al., 2011).

The objective of this study is to undertake public opinion research in order to identify what the public perception of fracking is in Ireland and to test the hypothesis of whether there is an overriding negative public perception of fracking in Ireland.
Literature

From reviewing previous literature, it is evident that there has been a vast amount of public opinion research on hydraulic fracturing but the research is predominantly based on studies in the USA. The literature in this area considers focusing on socio-demographics; perceptions of risks and benefits; affective imagery; geographic proximity while investigating the public’s perception (Scheutele et al., 2005). Research by The Pew Research Centre for the People and the Press (2012) identified that 80% of the people with a college degree had heard of hydraulic fracturing while only 51% with a high school diploma or less had heard of it.

Research by Lorenzoni (2006) highlights that affective imagery can affect us on how we view risks and benefits. For example Leiserowitz (2006) outlined that one reason climate change is of low concern to American citizens is because it invokes distant images that have non-human risks. If you apply this research to hydraulic fracturing it would suggest that support or opposition is influenced by positive or negative images. On one side you have images of contaminated water and large drilling pads and on the other side you have positive images of economic growth and job creation. It is important to apply this to the survey for the study and include the following research question:

*Do you have a positive or negative image when you think of the word hydraulic fracturing?*

A recent study by Jaspal (2014) highlighted how media plays a strong role on influencing the image of hydraulic fracturing. Opposition to fracking in Poland is seen as being anti-Polish and the media have painted fracking as a positive technology which will be of great benefit to the country. The reason for this is because the media reports the geopolitical aspects of fracking and not the scientific aspects. The following research question will be included in the research in order to gain data on the influences of Irish media:

“What forms of media do you think most influence peoples view on hydraulic fracturing?”

Methodology

Based on the findings of previous research from the literature review a set of questions will be established to help test the hypothesis of whether there is an overriding negative public perception of fracking in Ireland. The survey will compare the village of Belcoo in County Fermanagh with Tang in County Westmeath. Tamboran Resources completed a borehole test during the summer of 2013 in Belcoo. According to the census Belcoo has a population of 1,415 and Tang has a population of 900. The two selected case studies have similar demographic characteristics which will allow for a fair comparison. An online survey will also be developed to enable a larger response to the survey. Descriptive statistics will be used to analyse the data. Likert scale and Chi square will also be used as analysing tools.

Sampling

The sample size for both case studies will be 300. A random sample of houses will be chosen for the study. The primary approach will be to conduct face to face using a print out of the survey. The other approach would involve advertising the online survey in the local media. The survey will be conducted from the 1st of March until the 31st of March. The target time to complete one survey is four minutes.

Questionnaire and Analysis

The questionnaire for this study will be divided into sections of public perception, the sections will be as follows:

*Section One: General*
*Section Two: Familiarity with Hydraulic Fracturing*
*Section Three: Impact of Hydraulic Fracturing*
*Section Four: Social Impacts of Hydraulic Fracturing Section*
*Section Five: Economic Impacts of Hydraulic Fracturing*
*Section Six:*
Personal Opinion of Hydraulic Fracturing

The questions will be primarily measured using a five point Likert Scale from strongly disagree to strongly agree (Baxter et al. 2013). The Likert Scale involves calculating the mean and the standard deviation. Chi square will also be used during the analysis of data because it will let us know whether the two groups in the case study have significantly different opinions.

Target Population

Two case studies will be conducted, the first will be the area surrounding the proposed fracking site in Belcoo, Co. Fermanagh. The surveys will be conducted within a 20 km radius of the site. This will include county Cavan and Leitrim. The second study will be conducted in Tang, Co. Westmeath; it is located on the border with Longford. The reason for selecting Tang is because it is of similar demographics to case study one.

Results and Discussion

The research is currently underway therefore only expected results can be addressed. The results from each case study have the possibility of being very different. Case study one has been in the media frequently over the last 12 months and it is expected that most responses in the area will oppose hydraulic fracturing; it is important to explore the reasons behind people’s opinions. It is expected that case study two will not have such a strong negative opinion on the technology because it has not been exposed to hydraulic fracturing companies hoping to develop in their community. Further research and data analysis will test the hypothesis of whether there is an overriding negative public perception of hydraulic fracturing in Ireland.

Conclusion

This research will identify the concerns Irish people have surrounding hydraulic fracturing. The debate of whether the economic benefits justify the risks will be explored through the survey and as a result the research should illustrate what people’s views on hydraulic fracturing are and how they are influenced.

References


INTEGRATION OF A BIOREFINERY WITH A LOCAL COMMUNITY: A FEASIBILITY STUDY

Nathan O’Sullivan¹, Kevin McDonnell¹, Deirdre Lynch²
¹UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.
²Carbolea Research Group, Chemical & Environmental Sciences, University of Limerick, Limerick, Ireland.

Abstract

In 2006, Ireland’s transport sector consumed circa 41.4% of the final total energy. Of the 41.4%, biofuels accounted for 0.05%. The Biofuels Directive 2009/28/EC in tandem with Ireland’s White Paper ‘Delivering a Sustainable Energy Future for Ireland’ set a 2010 target of 5.75% biofuels penetration, which was not met, and a 2020 target of 10% which is looking increasingly unlikely. As such the need for more and more biorefineries here in Ireland is essential and small-scale start-ups could have the potential to lead the way for larger scale installations.

Introduction

Ireland is a net importer of energy. According to the World Bank, in 2011, Ireland imported 86.47% of its total energy. This is a trend that has fluctuated little over the past number of years. As Ireland is increasingly dependent on energy supplies from other countries, it is paramount to find a sustainable alternative to imports sooner rather than later.

There are a plethora of renewable energy options available, especially for domestic energy supply. However, for the transport industry, there are fewer options. The electric car has not been as much of a success as had been hoped, and while internal combustion engines are becoming more fuel efficient, they still rely on petrol and diesel for operation. Probably, the most obvious alternative choice is biofuels. They are steadily growing in popularity, as they are both renewable and combust similarly to conventional fuels. In Slovakia they have a 7.8% penetration (the highest in Europe) in their transport energy consumption figures (Cansino et al, 2012). Here in Ireland, biofuels have a 2.4% penetration, far off the 2020 target of 10%. As such, there must be a surge in biofuel production rates. Studies carried out by Tuohy et al, indicate that the best route for biofuels in Ireland is a revival of the sugar beet industry for large-scale production. However, these studies were carried out over four years ago and there has been little progress on the idea. Clearly there is a need to start small and based on the small-scale success/failure then potentially scale up. This project examines a small, local, suitable crop producing community. It will look at a small village/town (probably in the south of Ireland) and will determine the feasibility of installing an adequately sized biorefinery (to meet the crop production rate of the village/town) to the village/town, to see if it is financially and environmentally viable. Instead of viewing the residents of village/town as customers, they will be viewed as partners. The growers supply the feedstock and are subsidised with biofuel and possibly cheap electricity, heat and animal feed/fertilisers. Thus meaning the biorefinery has minimal feedstock costs, minimal waste, produces heat & electricity which it can sell as well as fertilisers and at the end of it all, contributes to carbon dioxide mitigation (Farrell et al, 2006).

The objective of this study is to determine if the installation of a small-scale bio refinery makes financial sense and to see if the community involved will benefit from it.
Method

Certain crops possess a structure that gives them the ability to be converted into biofuels. The structure is comprised of three main parts: 1) Lignin, 2) Hemi-cellulose and 3) Cellulose. For biofuel production, it is the hemi-cellulose and cellulose that this project is concerned with as these are the complex and simple sugars (respectively) that will be fermented and distilled into the biofuel (bioethanol). Lignin is insoluble and is subsequently a residual waste that can be collected and burned to fuel the distillation stage and/or used for the heat and electricity generation (or in some cases be sent for second generation biofuel production).

For ethanol production, the bio refinery can be simple just as easily as it can be complex. Its technology will depend on the input feedstock. In any case there are three fundamental steps for all feedstocks: 1) Pre-treatment, 2) Fermentation and 3) Distillation. Pre-treatment can be as simple as shredding the feedstock down to a smaller size or can be as complex as hydrolysis (which removes the insoluble lignin from the feedstock) enzymatically or with chemicals and temperature but regardless, it allows a greater access to (i.e. helps to liberate) the plants complex and simple sugars necessary for ethanol. After pre-treatment, the juice is extracted and then fermented producing the ethanol, which will then be sent for distillation to purify the alcohol. For fermentation, the liquid mixture just needs time to react with yeast in order to become an alcohol, typically 6-10 hours. From the fermentation tank, the batch is sent to be distilled, which removes any foreign substances, essentially cleaning the ethanol.

For this project, there are three different feedstocks under consideration, namely, wheat straw, sugar beet and rapeseed (for biodiesel). Each pose their respective positives and negatives, both with the material and the technology required to process the material. Importing a material (although it may be potentially cheaper) will entirely undermine the purpose of this study and as such has been ignored.

Table 1. Initial comparison of potential feedstock’s for the study (SEAI, Biofuel Factsheet)

<table>
<thead>
<tr>
<th>Process</th>
<th>Wheat Straw</th>
<th>Sugar beet</th>
<th>Rapeseed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop Yield (t/ha)</td>
<td>Complex</td>
<td>Simple</td>
<td>Simple</td>
</tr>
<tr>
<td>Fuel Yield (l/t)</td>
<td>384.62</td>
<td>107.53</td>
<td>434.78</td>
</tr>
<tr>
<td>Energy Content (MJ/l)</td>
<td>21</td>
<td>21</td>
<td>34</td>
</tr>
</tbody>
</table>

Wheat straw has a winter and summer harvest. In 2010, Ireland produced 401,380 tonnes of winter wheat and 160,740 tonnes of summer wheat (Teagasc, Straw for Energy Fact Sheet). The reason for a higher winter wheat yield is that it has a longer growing period. Obviously, not all wheat straw can be converted into bioethanol, as some will need to be ploughed back into the field to act as a fertiliser. But there is good indication of an enormous fuel yield from wheat straw. The production of bioethanol from wheat would require enzymatic hydrolysis in order to liberate the maximum amount of ethanol possible from the feedstock. As such, this is a costly process however, the residual lignin can be used as fuel for the plant or can act as a saleable fertiliser; regardless, it can generate some revenue.

Sugar beet was once a thriving crop here in Ireland but the closure of the sugar industry took the sugar beet crop plantations with it. However, it is known that conditions here allow for a good yield of sugar beet crops. Bioethanol from sugar beet is a much simpler process than wheat, as there is no hydrolysis required. The sugar beet is milled down to a smaller particle size and then crushed to extract the juice. This juice then goes on to be converted into ethanol. The residue can be further processed into second-generation bioethanol however, it is
anticipated that the waste will act as animal feed. It is included at this stage of the research to keep options open in case of a change in the plan further down the line of the research.

Rapeseed produces biodiesel. Rapeseed oil can be used in blends with diesel in newer engines however, in older engines, it will need a bit of treatment to clean the fuel. Ireland has the potential to produce some 216 kilotonnes of winter rapeseed oil (Rice et al, 2006). This means that it can certainly go a long way towards achieving the 10% penetration goal set out by the European Biofuels Directive. Like sugar beet, it is not the most energy intensive process requiring just compression. However, the oil that is produced does not always conform to current fuel standards such as EN 14214. New engines and modified engines will be able to tolerate biodiesel produced after extraction, however if the oil is to be used in older engines, then the oil will have to be further treated with potassium hydroxide and methanol.

Once a feedstock and subsequent technology has been settled upon, the energy demand (both electrical and heat) for a village/town will be examined. This demand will be the basis upon which the bio refinery will be scaled to. The primary output will be the bioethanol for the wheat straw and sugar beet and if using rapeseed, then biodiesel.

Alongside all of this, the financial aspect will be monitored. This technology will probably be quite financially intensive as there will be fees associated with testing, planning, purchasing of technology, construction and wages to name a few. Of primary interest here is the financial partnership between the refinery and the community. Striking a deal that is beneficial for both parties is fundamental to the success of this project. It is expected that the refinery will produce excess fuel, heat and electricity (after serving the village/town) as it will require revenue in order for it to survive. This will be factored into the sizing of the refinery.

It is planned to undertake a survey in a likely village/town to get the residents opinion on such a project. As with any project like this, it is anticipated that there will be some objection to some aspect of the project. A key part of this project is liaising with the community, allowing the residents to be deeply involved with the project step by step as community co-operation is fundamental to the success of the project.

**Results and Discussion**

The study is still very much in its infancy and as such there is no concrete results as of yet. As already mentioned, it is anticipated that the survey will have some opposition towards the concept; the survey aspect should be able to quantify that element. Influencing the public perception will be essential if the consensus indicates negativity. Initial reading on the feedstocks and technologies is varied. Sugar beet seems to be the optimum feedstock however, seeing as it is no longer grown here in Ireland, it would merely be hypothesizing. There is ample supply of wheat straw however, the technology required is more intensive than sugar beet and as such, expensive. Rapeseed is a potentially suitable candidate, however, this is for biodiesel and would require further processing with chemicals to ensure it would conform to fuel quality regulations. Perhaps accommodating for both bioethanol and biodiesel could be another opportunity to venture towards and its viability will certainly be examined.

**Conclusions**

In conclusion, it is clear that there is significant potential for this project. Settling on a clear scope as soon as possible is important. The village/town for the study needs to be finalised as well as the feedstock. Once this is completed, sizing the plant to the communities needs will follow next and then examining the products and by products for both the community and as a source of revenue for the plant will be the last phase.
References


FEASIBILITY OF SIZING A NEW CHP PLANT IN UNIVERSITY COLLEGE DUBLIN AND TO ASSESS ECONOMIC AND ENVIRONMENTAL IMPACTS OF DIFFERENT CHP TECHNOLOGIES

Tenzin Tashi, Patrick Grace
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

The world population expansion is predicted to be about 8.97 billion by 2050. This will lead to a rise in energy demand and climate change. Thus, there is a need for highly efficient technology to cope up with the energy demand and climate change problem. Combined heat and power, which typically having an efficiency of 80% is one such technology. In Ireland, Government’s Energy White Paper had set a national target for CHP to be 800 MWe by 2020. In 2013, the installed CHP capacity was 308 MWe and an addition of 492 MWe is required to meet the national target of 800 MWe by 2020. In this project, the feasibility of sizing a new CHP in University College Dublin Belfield campus to replace the old CHP will be assessed. The economic and environmental impacts of different CHP technologies will also be assessed. Various factors affecting the sizing of new CHP will be analyzed. In this project, Electricity, heat and gas consumption data of UCD Belfield campus are used from the Cylon Active Energy Manager. It is anticipated that the most efficient and reliable CHP technology will be chosen. This will assist in meeting the national target of 40% electricity from the renewable energy sources by 2020.

Introduction

Combined heat and power (CHP) produces both electricity and heat in a single process, unlike conventional power plant in which only electricity is produced and no heat is recovered. CHP technology provides a highly efficient and secure source of electricity and heat. It is anticipated that for every 1MW capacity of CHP, it reduces a ton of CO₂ per annum (SEAI). Government’s Energy White Paper published in March 2007 set out a national target for installed CHP capacity of 400 MWe by 2010 and 800 MWe by 2020. According to 2014 SEAI CHP report, the estimated operating CHP capacity was 308 MWe in 2013. Natural gas CHP was the main contributor accounting for 282.4 MWe from total CHP capacity. Biogas and Biomass contribute about 6.3MWe and 5.4 MWe respectively. Ireland’s total electricity generation from CHP was 7.4% and total thermal energy demand met by CHP was 6.5% in 2013. Even though there is a gradual increase in the installation of CHP, in order to meet 2020 target of 800MWe, an additional capacity of 492 MWe will be required (SEAI CHP 2014).

Currently in UCD Belfield campus, there are two CHP each with 1.1MW rated capacity generating electricity and heat. This CHP plant supplies electricity to the university and accounts for approximately 35% - 40% of total university electricity demand. The recovered heat from the CHP is dissipated to the District Heating System. This DHS is connected to the majority of the UCD buildings. Apart from heat supplied from CHP, there are two condensing gas boilers each with 1.75 MW and one biomass (wood pellets) boiler of 0.95 KW. These boilers supply heat to the District Heating System. Furthermore, one unit of 6MW gas boiler is installed solely for the back up purpose during outage of other heat sources. Since the CHP was installed in 1999 and has a lifetime of 15 years, it has to be replaced by a new CHP. Therefore, in this project, a feasibility study will be carried out for sizing a new CHP and also various CHP technologies will be assessed in accordance with the new size of the CHP. Moreover, the economic and environmental impacts associated with different CHP technologies will be evaluated. Cylon Active Energy Manager database will be used for the feasibility study along with information data from other sources.

The objective of this project is to assess the feasibility of sizing a new combined heat and power (CHP) in UCD Belfield campus and to assess economic and environmental impacts associated with different CHP technologies available such as Biomass CHP, Biogas CHP and Natural gas fuel CHP in accordance with the new size CHP.
**Materials and Methods**

Electric and thermal load of the UCD Belfield campus data have been taken from Cylon Active Energy Manager, and other information data required for this project will be taken from journals, different manufacturers, and reports, etc. The feasibility of sizing a new CHP will be carried out from Cylon Active Energy Manager database, which monitors electricity, heat and gas consumption of all the UCD Belfield campus building. In addition, the feasibility of various CHP technologies such as Biomass CHP, Biogas CHP and Natural gas fuel CHP will be assessed according to the new CHP size. Eventually, the most efficient and reliable CHP technology will be chosen.

**Desktop study**

UCD being the largest third level institute in Ireland, an effort had made to make UCD campus into a vibrant 21st century modern smart campus. Thus, a campus development plan was drafted in 2005 under the title “Sustainability, Healthy and Living Campus”, which not only focused on academic, but also on the energy management of the UCD buildings. This energy management aimed to cut the energy cost and to reduce greenhouse gas emissions. The Energy Centre in UCD Belfield campus monitors the electricity consumption and gas consumption of over 50 buildings on a 132 hectares site using Cylon Building Management System (BMS).

UCD typically uses about 100 GWh of energy each year, from this, UCD Belfield campus energy usage approximately accounts for 90%. An estimate of 35% - 40% of electricity usage of the UCD Belfield campus is generated from the CHP plant on-site and the rest of electricity demand is imported from grid. From the 2013/2014 data, total cost of energy expenditure was 7.5 million euros, of which 60% accounts for electricity cost, 35% for gas cost and 5% for a wood pellets cost. CHP installed on-site in UCD Belfield campus was sized according to the campus base electric load. Typically, the efficiency of CHP (cogeneration) plant is approximately 80% (SEAI CHP 2014).

There are two CHP (total of 2.2 MW rated capacity) currently operate in the Energy Centre on UCD Belfield campus. The operating hours of CHP is from 8am to 11 pm (Monday to Friday) and only one engine operates during Saturday and Sunday. This plant supplies electricity into the campus (10 KV distribution Network) and heat produced is dissipated into the university District Heating System. This District Heating System is connected to the majority of the buildings to supply heat and hot water, which are located adjacent to the central spine. However, apart from the heat supplied from the CHP, there are two condensing gas boilers (each of 1.75 MW), one Biomass (wood pellets) boiler of 0.95 MW, and one 6 MW gas boiler solely use for back up purpose during plant outage of other heat sources. The biomass boiler currently runs for a 6 months period from October to March and operates between 6am to 5pm.

![Figure 1. Difference between Conventional Power Plant and Combined Heat and Power (CHP)](image-url)
Table 1. Technical details of existing CHP reciprocating engine

<table>
<thead>
<tr>
<th>Engine type</th>
<th>$2 \times$ JMS 320 GS-N.L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical output</td>
<td>2012 KW</td>
</tr>
<tr>
<td>Thermal output</td>
<td>2544 KW</td>
</tr>
<tr>
<td>Electrical efficiency</td>
<td>38.80%</td>
</tr>
<tr>
<td>Thermal efficiency</td>
<td>49.06%</td>
</tr>
<tr>
<td>Total efficiency</td>
<td>87.86%</td>
</tr>
<tr>
<td>Bore/Stroke</td>
<td>135/170</td>
</tr>
</tbody>
</table>

Factors considered for sizing of new CHP
Since the CHP plant is near to its end life, a feasibility study on sizing of new CHP will be assessed to evaluate the possibility of increasing the size of new CHP to energy cost. This project will be focusing on the procurement of the new CHP solution, which proves to be an economical, reliable and sustainable for the UCD Belfield campus. The sizing of new CHP will be assessed according to the various factors affecting the electricity and gas consumption from 2012 to 2014. The data from Cylon Active Energy Manager for electricity, thermal and gas consumption of UCD Belfield and old CHP from 2012 to 2014 are shown in the table below.

Table 2. UCD Belfield electricity, heat and gas demand data and supply data from CHP plant from 2012 to 2014

<table>
<thead>
<tr>
<th>Year</th>
<th>UCD Belfield</th>
<th>CHP 1 + CHP2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electricity (Kwh)</td>
<td>Heat (Kwh)</td>
</tr>
<tr>
<td>2012</td>
<td>33.80×10⁶</td>
<td>9,600,746</td>
</tr>
<tr>
<td>2013</td>
<td>36.23×10⁶</td>
<td>17.64×10⁶</td>
</tr>
<tr>
<td>2014</td>
<td>34.68×10⁶</td>
<td>15.93×10⁶</td>
</tr>
</tbody>
</table>

To evaluate the potential in the sizing of new CHP, a various parameters affecting the outcome will be assessed. Several factors are considered under this project and they are 1) seasonal and monthly variation of the electric and thermal load of UCD Belfield campus, 2) quality and availability of the fuel (biomass, biogas, and natural gas), 3) future changes in on-site electric and thermal load demand due to future campus development plan, 4) Market barriers and risk associated with different CHP technologies, 5) government incentives available for the deployment of the CHP, 6) efficiency and reliability of the system, 7) operating hours of the CHP plant, 8) whether to connect system to the grid or not, and 9) heat to power ratio. The feasibility of sizing a new CHP will be based on the result obtained from these various parameters analysis.

Feasibility of different CHP Technologies
Furthermore, in this project, various alternative technologies such as Biomass CHP, Biogas CHP and natural gas fired CHP will be evaluated in accordance to the new size of the CHP. The different CHP technologies will be evaluated thoroughly in terms of fuel quality, fuel availability, equipment cost, environmental impacts associated with these technologies during operation and availability of technologies in the market to suit the new size of the CHP.
Result and Discussion

As this study is in its initial phase, it is difficult to predict the result. However, it is anticipated that the result will be the one, which selects the most efficient CHP technology (Biomass CHP, Biogas CHP and natural gas fire CHP) for the new CHP. New CHP size will be finalized from thorough analysis of several factors affecting electric and thermal load of UCD. The result obtain is expected to reduce the cost of electricity and cut the greenhouse gas emissions, thereby making the UCD Belfield campus environmentally sustainable.

Conclusion

This project will evaluate the feasibility of sizing a new CHP plant in UCD Belfield campus from the electricity, heat and gas consumption data of all the buildings from the Cylon Active Energy Manager. In addition, the various CHP technologies available such as Biomass CHP, Biogas CHP and Natural gas fired CHP for the new CHP will be analyzed. After analyzing the various factors, sizing of the new CHP will be finalized. Eventually, it is anticipated that the most efficient and reliable CHP technology chosen will reduce the greenhouse gas emissions and will contribute towards Ireland’s CHP target of 800 MWe and also to the 40% electricity from the renewable energy sources by 2020.

References

SEAI (February 2006) CHP in Ireland Options for a National Policy to 2010.
Unit, B. R. U. E. 'Cylon Active Energy Manager', [online]
FOOD WASTE VALORISATION: PRODUCTION AND CHARACTERISATION OF BIOPOLYMER FILMS FROM MILK DERIVED PROTEIN

Rashi Goyal, Aoife Gowen
UCD School of Bio-systems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

In Ireland, one of the major food industries is the dairy industry and one of the most important waste products is casein. In this paper, the production of biopolymers from milk derived protein (e.g. sodium caseinate) is studied. Key parameters affecting the acceptability of such biopolymer film includes optical transparency, mechanical flexibility, and oxygen barrier strength with their biodegradability. The overall aim of this study is to characterise biopolymer films prepared from sodium caseinate using hyper-spectral imaging. In this paper an introduction to preparation of the biopolymer films processed from industrial food waste and the methodology required is presented in advance of the experimental studies which will take place later.

Introduction

Despite the essential importance of food in human life, a very large amount of edible and not so safe food is wasted every year. The definition of food waste varies vastly among various literatures. A simple and general definition could be stated as the food that is not being used or consumed. This is owing to different reasons like expired, non-edible, damaged, etc. According to research from the British based Institution of Mechanical Engineers (IME), roughly 4.4 billion tonnes of food is produced every year out of which half of the food was wasted, in 2013. Although, it is very difficult to classify the food waste into different categories as they differentiate in terms of their nutritional composition (e.g. protein, carbohydrate, etc.), contents, source they are coming from and their consumption. The study performed by the EPA on national waste characterisation in 2008 is a key source for this data. In the European Union, food wastage issues are by food and agricultural organisation, FAO. But their current existing data and scenarios are too generalized to create a normalised data set for every individual country. On the basis of prevention of food waste for both categories, they can be divided into three basic types; avoidable, potentially avoidable and unavoidable.

Food waste regulations (SI 508 of 2009) came into force in Ireland on July 1st, 2010. This regulation was aimed to establish bin systems, according to which the major producers of food waste will have to segregate food waste at the source and also ensure that it is not being mixed with other waste. All the food waste should be categorised and segregated for recycling by the brown bin collection services. Currently, the re-cycling rate of food waste generated by businesses is very low less than 10% (Schneider et al 2013). However, this legislation was particularly designed to ensure and certify all the major sources of food waste make their contribution to increasing national level of recycling and to obey EU legislations. According to the EU legislation and landfill directives, Ireland, like every other European country, has to reduce the amount of waste sent to landfill by a series of targets. If not, Ireland will have to pay significant fines. This leads us to utilize food waste as a resource i.e. food waste valorisation.

The objective of this project is to prepare and characterise different properties of sodium caseinate films with different plasticizer (glycerol and sorbitol.)
Materials and Methods

Food Waste as Resource

Average food waste in different regions of the world is shown in Figure 1. The majority of food waste is seen in the food supply chain and value chain every year. This is due to unproductive or ineffective technical and management systems, overstated expectations, lack of maintenance issues in and outside the food supply system and many more. This food supply chain waste (FSCW) could lead to a negative impact on various sectors of society like economic, ethical, environmental and social. There is now a noticeable recognition that the twin issues (food waste management and resource depletion) can be solved collectively through using food waste as a resource, using various technologies. Further, we need to make sure that these technologies (e.g. chemical, bio-gasification, bio-polymerisation, etc.) should be cost effective and sustainable. These food waste or feedstock still contain huge amounts of organic content with various physio-chemical properties, wide-ranging calorific values, moisture content, nutrients and many other components depending upon the type of food. This is why they are considered as valuable resources with significant potential. They are used as renewable raw material in production of the different higher value products. In recent decades, many examples illustrating food waste valorisation like waste cooking oil, citrus peel, resins, cashew shell nut liquid, milk derived polymers etc. came to public interest countries like China, Tanzania, Spain, United Kingdom, USA and more. This improves food waste valorisation, reduces the landfills leads to benefit the overall municipal waste management at some level. Other routes of food waste valorisation are described in figure 3. Therefore, research and development regarding post processing of waste from food industries is of increasing interest.

Biopolymers are polymers produced by organic sources; i.e. from renewable matter such as protein (e.g. sodium caseinate), starch and glucose. They are highly degradable as compared to standard polymers (e.g. PVC, PET, PE etc.) hence less damaging to the environment. These biopolymers are transformable, easy structural design and biodegradable which makes them more apt as a resource. However, certain properties of such biopolymers are often unacceptable (e.g. water sensitivity, mechanical strength, flexibility). Casein is the principle protein found in cow’s milk that has been extracted for many centuries now. Acid casein, rennet casein and

![Global Annual Food Waste in Million tons](image)

**Figure 1** Average global food waste of different regions of world, IME.

![Different food waste valorisation routes](image)

**Figure 2** Different food waste valorisation routes
sodium (calcium, potassium etc.) caseinate can be used in several industrial application like food (cheese production, bakery, dairy products, ice cream production, sports drink etc.), pharmaceuticals, paper products, paints and plastics (replacing petroleum based polymer). Caseinate is produced by dissolving precipitate casein by means of sodium hydroxide, sodium phosphate or calcium hydroxide. So, sodium caseinate is a biochemical name given to casein proteins, with better protein content.

In this research project, characterisation of biopolymer films prepared from sodium caseinate is studied. Casein and caseinate has taken up by the food industry to develop biopolymer films for the packaging technology, reducing the solid waste and pollution. Properties like transparency, biodegradability and barrier between food & the gases like O2 and CO2) makes them an innovative material for such application. Their antibacterial property also adds to commercial potential for this application. However, research shows that limitations such as water sensitivity and mechanical properties add a few negative points to this sustainable approach. To overcome the mechanical strength, plasticisers have been added, such as polyols (glycerol and sorbitol), sugar and starch. Other limitations can be altered by adding modifiers such as oil (oil resin), waxes (oleic acid and beeswax mixture), acetylated monoglyceride etc. These biopolymer films or ‘active food packaging’ can be a great alternative food packaging technology as compared to the previous technology used.

Methodology
Recent research has shown the production of biopolymer film prepared from sodium caseinate is quite a straightforward process. However, they are generally brittle unless plasticizers are added (e.g. glycerol, sorbitol). To reduce their sensitivity towards water, researchers have modified the biopolymer by adding oil resins, waxes etc. as modifiers.

Using various studies, a method can be designed for the preparation of sodium caseinate films. These biopolymers can be prepared by dissolving 5 g of sodium caseinate with 95 g of distilled water. To help the solution properly dissolve, it should be heated at 65 degrees Celsius, after which the solution should be allowed to cool down at room temperature. Then, different percentages of modifier like glycerol (plasticizer) will be added to the prepared solution. The percent of glycerol could vary from 15% to 35% for different solutions. After dissolving in water, 30 ml of each solution is to be placed in 15 cm diameter polyethylene Petri capsules to dry for 48 hours under controlled temperature and humidity conditions (25ºC and 50% relative humidity). This will provides a fine thermoplastic plasticized material. The biopolymer film will then be taken for various assessments like hyperspectral imaging, mechanical strength, water sensitivity, etc. The most important assessment is to test their biodegradability (Martucci and Reseckaite (2009) method). This test will determine the real commercial potential of these films, benefiting the food waste management. To ensure the food quality and safety control its antibacterial activity will also be studied.

Conclusion
The conclusion can be made that categorisation of food waste is difficult yet an important aspect of foods waste valorisation and solid waste management for example to use food waste as a resource. Casein, which is already a very useful additive in various food and non-food industries, will be used to prepare a biopolymer films. From this study, so far it can be concluded that biopolymer film made from the milk protein i.e. sodium caseinate has huge potential in the food packaging industry. This is owing to its easy and fast production (from biopolymer), technical strength, optic-transparency and most important it’s biodegradability. Addition of different modifiers can alter biopolymer strength and limitations. This will be studied experimentally in this project.

Acknowledgement
The author acknowledges the assistance of Dr. Aoife Gowen, UCD School of Bio-systems Engineering.
References


Southwest, C.R., Consumer and Application Science Section, Dairy Research Institute (New Zealand).

www.foodwaste.com
EVALUATING IRISH ENVIRONMENTAL RESEARCH 1991-2015

Mugdha Karmarkar¹, Paul Bolger², Thomas Curran¹
¹UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.
²Environmental Research Institute, University College Cork, Lee Road, Cork, Ireland.

Abstract

Various human activities have given rise to many environmental problems. Environmental research is very important to maintain a balance in the ecosystem. Research helps to analyse the problem and create an awareness among policy makers and the public. In this study, it was considered appropriate to evaluate Irish environmental research trends in the period 1991-2015 as it coincides with the 25th anniversary of ENVIRON, the largest annual environmental research conference in Ireland. The Irish Environmental Protection Agency (EPA) has been in existence for almost all of that timeframe too and is a key funding body for research. Between 2007-2012, the EPA has funded over 140 research projects in the field of sustainability alone. The trends in the type of research that is being done has to be analysed in order to establish a better understanding of where Ireland stands with respect to being a pioneer in environmental awareness and research. This study will help to understand the ever-changing landscape of environmental research in Ireland.

Introduction

Conservation of the environment is a matter of concern worldwide. Over the past few decades, government, environmental non-governmental organisations, public service and other communities have realised the importance of environmental research (Possingham 2000). Various issues like the decreasing water quality, loss of biodiversity and decrease in environmental health have been studied over the years.

The Environmental Sciences Association of Ireland (ESAI) is a network of individuals working in the environmental area. It is an organisation which encourages eminent researchers and scientists working in the environmental area to come together. This association is strongly connected to the Irish environmental research community and organises the largest annual environmental research conference known as ‘ENVIRON’ in Ireland (ESAI 2011).

ENVIRON is an excellent platform for researchers in the environmental sector to embellish their research. The conference has been encouraging scientists since 1991 to study more about methods to conserve the environment.

The fragile relationship between environmental security, sustainability and human activities have been the focus of study for many. Over the decades this topic has gained a lot of importance and this is clearly evident from the number of delegates choosing this subject for research (Myers 2004). The environment is a multidisciplinary field for research.

As ENVIRON celebrates its silver jubilee, a study is been carried out to ascertain the changing trends in Irish environmental research from 1991-2015.

There has been subtle changes in the themes of the ENVIRON conferences and these changes point towards the increasing knowledge of environmental conservation and the extensive research which are going on in this field (ESAI 2011).

The objective of this paper is to study the changing trends in environmental research in Ireland over the period 1991-2015.
Materials and Methods

The desk study will consist of a literature review and analysis of ENVIRON proceedings, journal publications and funding reports. It will be a study for the period of 1991-2015 in Ireland. In this research paper, a sample of the ENVIRON handbooks including the abstracts were analysed.

The number of ENVIRON delegate registrations is being compiled to determine the degree of interest in environmental research. A preliminary analysis was carried out using Wordle; this is a web-based software which gives greater prominence to the words which are frequently used in the submitted text (Feinberg 2013).

Results and Discussion

The data was plotted and classified according to themes given in the ENVIRON handbooks. The most common topics observed in the initial sample years 2011, 2012 and 2013 are Water Quality, Climate change and Energy, Environmental Management, Biodiversity, Environmental Health, Marine & Coastal Research. The total number of oral and poster presentations are presented in Table 1.

The number of delegates who attended the colloquium was 242 (year 2011), 285 (2012) and 276 (2013). There was a general increase in the number of delegates over the years possibly because of the platform provided for delegates from a wide variety of disciplines and background. Also, it is a very good chance for the delegates to acquire knowledge outside of their own research.

As per Table 1 different themes were allotted for each of the years. The topics for presentations and posters were chosen by the host college. Some of the topics appeared on a regular basis from year to year. Similar analysis was done for all the years and word clouds were generated using the Wordle.net website. For this, all the abstract titles under the session topics were merged into the website. The word cloud illustrates the prevalent areas in which research has been carried out.

Figure 1 shows the examples of word clouds done for years 1991 and 2015. Ireland obviously featured heavily along with wastewater but there were subtle differences between these years.

Figure 1. Word clouds for the years 1991 and 2015
Table 1. Table shows the Environ topics for 2011-2013 and the number of oral and poster presentations

<table>
<thead>
<tr>
<th>Date &amp; Year</th>
<th>Location</th>
<th>Theme of the Colloquium</th>
<th>Topics</th>
<th>Number of Oral Presentations</th>
<th>Number of Posters</th>
</tr>
</thead>
<tbody>
<tr>
<td>6th-8th April 2011</td>
<td>University College Cork</td>
<td>&quot;Towards 2020-: Environmental challenges and opportunities for the next decade&quot;</td>
<td>Water Quality</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Biodiversity &amp; Ecosystems</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Energy &amp; Climate Change</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Environmental Management</td>
<td>13</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Environmental Technologies</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Marine &amp; Coastal Research</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Environment &amp; Health</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>7th-9th March 2012</td>
<td>University College Dublin</td>
<td>&quot;Our Environment : Integrating Today's Research with Tomorrow's Actions&quot;</td>
<td>Climate Change</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Environmental Technology</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Biodiversity &amp; Ecosystems</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Water Quality</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Energy</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Environmental Management</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Marine &amp; Coastal Research</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Environment &amp; Health</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>30th Jan-1st March 2013</td>
<td>NUI Galway</td>
<td>&quot;Ecosystem Functioning to Human Health&quot;</td>
<td>Environment &amp; Health</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Climate Change &amp; Energy</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Biodiversity &amp; Bio resources</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Socioeconomics &amp; Environmental Policy</td>
<td>14</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Water Quality</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Environmental Management</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ecosystem Services</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Marine &amp; Coastal Processes</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Environmental Technologies</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>
Conclusion

The initial analysis was done by using the data from a sample of ENVIRON handbooks. Further analysis will be done by using publications, ENVIRON handbooks and funding reports. A brief analysis from this paper was presented by Dr. Richard Thorn at the 25th Irish Environmental Research Colloquium at IT Sligo. The presentation gave an overview of the changing trends in environmental research in Ireland. The word clouds generated for two years 1991 and 2015 were included in the presentation. It highlighted the various changes that took place in environmental research over the years. Further interpretation of the data will highlight the various changes that have taken place in environmental research during the period.

Acknowledgements

The authors would like to thank the Environmental Sciences Association of Ireland for providing the reference material for the study.

References

ESAI (2013) in Environmental Science Association of Ireland, Galway, 3-225.
USE OF BIOMONITORS IN THE DETECTION OF AMMONIA EMISSIONS FROM INTENSIVE AGRICULTURAL UNITS IN COUNTY CORK

Aneesh P. Kale, David Kelleghan, Thomas P. Curran
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract
Ammonia emissions tend to have an adverse impact on the environment. Excess of ammonia serves to be harmful to nitrophobic plants in the environment. Intensive agricultural units are known to be a key source of atmospheric ammonia in the biosphere. In the environment there are several biomonitors present such as lichens and mosses which can be used to identify the levels of nitrogen in the environment. Moss cover, plant species richness and the Ellenberg-nitrogen indicator have been used in this study to assess the impacts of ammonia in areas around intensive agricultural units in Co. Cork. It is seen that mosses are more sensitive to atmospheric ammonia in areas where intensive agriculture is present. Thus they may act as indicators in detection and estimation of impacts of ammonia into the atmosphere from agricultural units. The study fits into the larger Ammonia N2K project, which has investigated these patterns on a national scale. Following on from previous work, this study reduces the impact of disperse relevés when assessing their sustainability to be used as biomonitors.

Introduction
Today intensive agricultural practices are known to be a key source of ammonia emissions in the atmosphere, accounting for 8% of Ireland’s 2012 emissions (Dowling, 2012). Ammonia concentrations can be high around intensive agricultural units and its release is known to have widespread effects on the environment. The nitrogen from ammonia settles on nearby lands, causing fertilisation. This favours plants which are tolerant towards nitrogen.

Acidification of land is also a direct result of increasing nitrogen content which creates unsuitable conditions for plant growth and eventually leads to loss of biodiversity (Hicks et al, 2011). In such a way excess ammonia emissions can upset an ecosystem in any conservation site if it is located around an intensive agricultural unit. In the environment there are key species that react in a positive or negative way due to changes in nutrient levels in the environment and thus help assert pollution levels in the area (Schröder et al, 2010). These are known as biomonitors. Key biomonitors for detection of ammonia are mosses and lichens. Of these, the nitrophobic species decrease in number with high increase in ammonia levels. However many nitrophilous species such as the orange coloured lichen, Xanthoria parietina are known to grow in abundance in high levels of ammonia.

As part of the study, the Ellenberg-nitrogen index which indicates soil fertility, can be applied to give a reading about an areas nutrient richness. This coupled with moss cover data is expected to provide an indication about the variation of ammonia around intensive agricultural units and further help in developing them as good ammonia detection sensors. Data from the NPWS Irish Grassland surveys for 2007-2012 for County Cork was selected as it had a high number of relevés. The study follows from a national assessment done by Wulf et al, (2015), which suggested that due to unequal distribution of relevés, there was a need to study the impacts of ammonia on a small scale. It will assist in assessing use of other biomonitors such as lichens in determination of ammonia content in the atmosphere.

The objective of the study was to use moss cover and the Ellenberg-nitrogen index value to detect ammonia emissions in different relevés around intensive agricultural units in County Cork.
Materials and Methods

The key data in the study is assessed with the help of the survey carried out by the NPWS on Irish semi-natural grasslands (O’Neill et al, 2013). The data from the survey is used to plot the relevés in County Cork around intensive agricultural units so as to provide values on the Ellenberg-nitrogen index and moss cover in the area. These are to be used as indicators in detection of ammonia in the local environment. A study conducted on impacts of ammonia emissions from intensive pig and poultry units on Irish Grasslands (Wulf et al, 2015) acts as a source of comparison for the current study in Co. Cork with respect to the rest of Ireland. Arc map 10.3 was used to show the position of the relevés and the spread of moss cover and the Ellenberg-nitrogen index around the intensive agricultural units. The data obtained through Arc map was then analysed for finding the mean value of the indicators at a threshold distance of 5 km. Buffers were created at a distance of 1, 5, 10 and 15 km, respectively. Depending on its location, these buffers helped in the identification and diversity of the indicators. These then assisted in estimating nitrogen content in the local environment.

Results and Discussion

Maps were plotted using Arc Map 10.1 for the Ellenberg-nitrogen value as well as moss cover. The mean for Ellenberg-nitrogen value and moss cover data was taken. It was seen that for the relevés in County Cork the mean value for the Ellenberg-nitrogen index was 3.57 while the mean for moss cover was 1.02. The spread of the values is seen below in Figure 1.

![Figure 1. Average Ellenberg-nitrogen value and average moss value around agricultural units](image)

Also as per Table 1, the average Ellenberg-nitrogen index value for the grasslands in County Cork is seen to be in low to moderate classes, i.e. it typically ranges from 3-5 while the average for moss cover in County Cork is generally between class 0-3 which means that in areas near the agricultural units the amount of moss cover declines if compared with areas away from it. Thus, moss cover shows a negative trend as it nears the presence of intensive agriculture.
Unlike most of the plants which acquire their need for nutrients from the soil, lower level species such as mosses tend to depend mostly on the nutrients in air (Boltersdorf et al, 2014). Because of this, mosses thus tend to be more successful in helping detect and estimate atmospheric N content in the local environment rather than vascular plants. As seen in Figure 1, more than 50% of relevés fall into the buffers around intensive agricultural units. The Ellenberg-nitrogen value is seen to be more or less static throughout. However moss cover is seen to be minimal near intensive agricultural units (Figure 2). The changes in moss cover with distance are a good indicator for changes with respect to atmospheric nitrogen around intensive agricultural units. A study in Northern Ireland (Sutton et al, 2011) on loss of bryophytes around a pig farm reaffirms data from this study. This further strengthens the validity of using moss cover as an indicator of atmospheric ammonia.

Results would vary if the study was to be done in other counties in Ireland and compared with the current study. Location of the areas, along with environmental factors such as soil quality, availability of nutrients may have played an important factor in determining the richness and presence of a number of species such as lichens, mosses, vascular plants, etc. in that area. Intensive agricultural units would most likely be of different sizes and would likely emit different levels of ammonia. It should also be noted that there are other sources of ammonia from other livestock farms, which are not taken into account in this analysis. If compared with previous studies (Sutton et al, 2011; Wulf et al, 2015) moss cover can be considered as a good indicator for detection of ammonia. Along with moss cover and Ellenberg-nitrogen index, data for species richness was also calculated but was not considered as part of the study.

Table 1. Percentage spread of samples for (a) Ellenberg-nitrogen Index and (b) Moss cover with respect to each class.

<table>
<thead>
<tr>
<th>Ellenberg-nitrogen Index (a)</th>
<th>Percentage Spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 0-1</td>
<td>0.88%</td>
</tr>
<tr>
<td>Class 1-2</td>
<td>1.76%</td>
</tr>
<tr>
<td>Class 2-3</td>
<td>6.19%</td>
</tr>
<tr>
<td>Class 3-4</td>
<td>38.93%</td>
</tr>
<tr>
<td>Class 4-5</td>
<td>48.67%</td>
</tr>
<tr>
<td>Class 5-6</td>
<td>3.09%</td>
</tr>
<tr>
<td>Class 6-7</td>
<td>0.44%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Moss cover (b)</th>
<th>Percentage Spread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 0-1</td>
<td>56.65%</td>
</tr>
<tr>
<td>Class 1-2</td>
<td>7.38%</td>
</tr>
<tr>
<td>Class 2-3</td>
<td>15.76%</td>
</tr>
<tr>
<td>Class 3-4</td>
<td>5.41%</td>
</tr>
<tr>
<td>Class 4-5</td>
<td>4.92%</td>
</tr>
<tr>
<td>Class 5-6</td>
<td>5.41%</td>
</tr>
<tr>
<td>Class 6-7</td>
<td>4.43%</td>
</tr>
</tbody>
</table>
Conclusions

The study is in line with previous research on impacts of ammonia emissions from intensive pig and poultry units on grasslands using moss data and Ellenberg-nitrogen index on a national level and are echoed in this paper.

When compared with the Ellenberg-nitrogen index, moss cover acts as a better indicator showing increases of nitrogen in the air. The moss cover data from the NPWS Irish semi-natural grassland survey, was used to generate the location of the relevés. When compared with the Ellenberg-nitrogen index, which was more or less evenly spread across the classes, the data for moss cover is potentially a better indicator. This further strengthens the use of moss as an indicator for ammonia emissions while also encouraging research on other biomonitors such as lichens for detection of ammonia.

Acknowledgements

The authors would like to thank the NPWS Irish semi-natural grasslands survey for providing the data for this study. They would also like to acknowledge work done by Wulf et al, (2015) which forms a comparison for the study. The authors would also like to thank both the EPA and the Northern Ireland Environmental Agency staff for information and support provided. This project is funded by STRIVE as administered by the Environmental Protection Agency. Further details of the project are available at: http://ssu.ie/research/ammonian2k/.

References


THE VALIDITY OF THE SCAIL AGRICULTURE MODEL AS A SCREENING TOOL IN IRELAND

Hugh McMahon, David Kelleghan and Thomas P. Curran
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Ammonia emissions from intensive pig and poultry units have been shown to have the potential to degrade ecosystems through acidification and eutrophication. The SCAIL-Agriculture model may be used as a preliminary screening tool in order to assess if intensive agriculture units have an effect on nearby Natura 2000 sites. The United States Environmental Protection Agency’s Screen View air dispersion model was used in this study as a comparison to the SCAIL-Agriculture model. Results between the two models varied greatly. The SCAIL-Agriculture model indicated that a selected poultry unit would have no significant impact on the nearby Natura 2000 site, contributing 0.01 ug/m³ of ammonia. The results from the Screen View model indicated that the poultry unit would have a much higher impact with ammonia concentrations as high as 235 ug/m³. Carrying out the same comparison of models on more sites and using the full version of AERMOD will establish how well the SCAIL-Agriculture model translates into an Irish context.

Introduction

The implementation of Food Harvest 2020 strategy by the Department of Agriculture, Food and the Marine aims to increase agricultural production by 33% by 2020 (Department of Agriculture, Food and the Marine, 2010). An important component of the Food Harvest 2020 strategy is to increase agriculture in a sustainable manner, preserving Ireland’s reputable status of producing ‘green’ sustainable produce. For this reason the increase in production must be coupled with the stringent environmental management of agriculture practices.

Ammonia (NH₃) can degrade the environment through the acidification and eutrophication of ecosystems, accelerate climate change and particulate NH₃ can have adverse effects on human health (Hayes et al., 2006; Philippe et al., 2011; Webb et al., 2014). Ireland emits an estimated 103.8 kt of NH₃ every year, with 98% of emissions being attributed to agriculture (Department of Agriculture, Food and the Marine, 2014). By 2050, global NH₃ emissions are expected to double as a result of increased intensive agriculture (Philippe et al., 2011).

The European Commission Acidification Strategy and the National Emissions Ceiling Directive aim to reduce ammonia emissions from agriculture and require ammonia levels to be monitored and reported annually to the European Commission and the UNECE under the Convention on Long-Range Transboundary Air Pollution. Emphasis has also been placed on the reduction of NH₃ emissions near ecologically sensitive sites under the EU Habitats Directive (92/43/EEC) and EU Birds Directive (2009/147/EC). This includes all Natura 2000 sites which is comprised of Special Areas of Conservation (SACs) and Special Protected Areas (Webb et al., 2014; European Commission 2015).

Basic air dispersion models allow for the preliminary assessment of the potential impact that intensive agriculture units can have on ecologically sensitive sites. Further research can be made using more advanced models (e.g. AERMOD) to assess the results of both screening tools.

The objective of this study is to compare the results of the SCAIL-Agriculture model to the Screen View model and assess its potential as screening tool for identifying the possible impacts that ammonia emissions from intensive agriculture units can have on Natura 2000 sites.
Materials and Methods

SCAIL (Simple Calculation of Atmospheric Impact Limits)-Agriculture is an atmospheric dispersion model which assesses the potential impact of intensive pig and poultry units on Natura 2000 sites in the United Kingdom. The model was originally developed for the Environment Agency by the Centre for Ecology and Hydrology and was then adopted by the Scottish Environmental Protection Agency in order to screen permit applications for farm units applying for planning permission. The model was further developed to be used in Ireland by introducing Irish meteorological data and data on Irish SACs and SPAs. The model focuses on the concentration and deposition of ammonia and can produce estimates for ammonia concentrations in close proximity of the source, which can in-turn be used to determine if levels will surpass the habitats impact limit and help determine if further screening is necessary. The model integrates components of AERMOD which is an atmospheric dispersion model developed by the U.S EPA, and incorporates meteorological wind data from Irish stations (Hill et al, 2014).

Screen View is an atmospheric dispersion model which models worst case scenarios for pollutant concentrations. The model determines in a straight-line trajectory the concentration of the pollutant as a function of the distance from the source and only allows for basic meteorological inputs. Similar to the SCAIL model, Screen View is a simplistic model which can determine whether further investigation is necessary in regards to the impacts of atmospheric emissions.

Model data for a selected site was obtained from aerial photographs, annual environmental reports and applications for integrated pollution, prevention and control licences which are issued by the Environmental Protection Agency for intensive agriculture units. The site chosen was a poultry unit located in Co. Cavan, located approximately 400m from a Natura 2000 site. Fan flowrate data was unavailable, as a result typical ventilation rates for poultry buildings were obtained from Seedorf et al (1998). Exact fan dimensions were unavailable but measurements were extrapolated from building plans.

Results

SCAIL-Agriculture model results:

<table>
<thead>
<tr>
<th>Concentrations/Depositions</th>
<th>NH\textsubscript{3} (ug/m\textsuperscript{3})</th>
<th>N Dep. (kg N/ha/yr)</th>
<th>Acid Dep. (kEq H+/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Contribution (PC) at receptor edge</td>
<td>0.01</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Background concentration at receptor edge</td>
<td>2.70</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Predicted Environmental Concentration</strong></td>
<td><strong>2.71</strong></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Process Contribution (PC) at receptor edge</td>
<td>-</td>
<td>0.08</td>
<td>0.005</td>
</tr>
<tr>
<td>Background deposition at receptor edge</td>
<td>-</td>
<td>32.00</td>
<td>4.42</td>
</tr>
<tr>
<td><strong>Predicted Environmental Deposition</strong></td>
<td>-</td>
<td><strong>32.08</strong></td>
<td><strong>4.43</strong></td>
</tr>
<tr>
<td><strong>Exceedance</strong></td>
<td><strong>1.71</strong></td>
<td><strong>27.08</strong></td>
<td><strong>4.14</strong></td>
</tr>
</tbody>
</table>

The results of the SCAIL-agriculture are displayed in table 1. The model indicated that the poultry unit had little effect on the SAC in comparison to background levels at the site. Background concentrations of NH\textsubscript{3} at the receptor edge were measured at 2.70 ug/m\textsuperscript{3} with the poultry units only contributing an additional 0.01ug/m\textsuperscript{3}. Overall, the NH3 levels at the site exceeded the limit by 1.71 ug/m\textsuperscript{3} indicating that the site exceeded its limit prior to the additional input from the poultry unit.

The model indicated that nitrogen and acid deposition as a result of the poultry unit had similar results with the poultry unit only contributing to a minor portion in comparison to background deposition levels at the site. Background nitrogen deposition levels were 32.00 kg N/ha/yr and background acid...
deposition levels 4.42 kEq H+/ha/yr with the poultry unit only contributing an additional 0.08 kg N/ha/yr and 0.005 kEq H+/ha/yr respectively. Both background values massively exceed limits prior to additional inputs from the poultry units.

Screen View Model results:

Results for the Screen View model are displayed below in figure 1. The first half of the figure displays the full results, showing concentrations as a function of the distance from the source. As expected the figure is a Gaussian distribution which shows concentrations decreasing significantly with distance from the source. The second half of the figure displays the first kilometre in more detail to allow for concentrations to be identified.

![Screen View model results](image1.png)

**Figure 1:** Screen View model results. The first graph represents the distribution of concentrations for 15km from the source. The second graph displays the first 1km from the site in more detail.

Figure 2 displays the site location, the SAC, wind rose and distances at 200m from the site. As can be seen, the closest SAC is located approximately 400m from the site. The wind rose indicates that winds come predominately from the south-west.

![Site location featuring a wind rose and proximity of near-by SACs](image2.png)

**Figure 2:** Site location featuring a wind rose and proximity of near-by SACs.

Discussion

The two models produced varied results. The SCAIL model indicates that the intensive agriculture unit does not contribute any significant increase to the concentration of NH₃ or the deposition of nitrogen/acids at the SAC. The additional values are negligible and only account for a small portion of
the overall levels at the site. The distribution curve generated by the Screen View model gives distinctly different values. The model indicates that the NH3 concentration levels from the poultry unit at the SAC (approx. 400 m distance) would be as high as 235 ug/m³. These large discrepancies in results may be attributed to meteorological data. The SCAIL model takes into account meteorological data when generating its results. As can be viewed from the wind rose in figure 2, the wind comes predominately from the south west. Therefore a majority of emissions would be directed away from the SAC which lies to the west. The Screen View model does not allow for detailed meteorological data to be input. Wind speed, direction cloud cover and stability class can all significantly effect the distribution of emissions in the atmosphere (Hayes et al, 2006). An important consideration is the difference in the functions of the models. Screen View generates a ‘worst case scenario’ downwind of the site, whereas SCAIL-Agriculture predicts the impact on a sensitive ecosystem in close proximity. In this example, the site is located upwind of the most frequent wind direction, a factor which the SCAIL-Agriculture model takes into account. Therefore carrying out the same assessment at more locations may determine the extent to which the results differ between the two models.

Conclusion

The preliminary results presented here are a promising indication that the SCAIL Agriculture model could be used as a screening tool to assess the potential effects that intensive agriculture units may have on Natura 2000 sites in Ireland. In order to validate the model further, more studies are necessary at a variety of sites. In addition to this, a full version of AERMOD could be used in order to assess the discrepancies between the results. SCAIL-Agriculture is used by the Environment Agency and Scottish Environmental Protection Agency regularly, so further research will determine how well the model translates into an Irish context.

References

USING GEOGRAPHICAL INFORMATION SYSTEMS TO SCREEN SPECIAL AREAS OF CONSERVATION AGAINST ATMOSPHERIC AMMONIA

David Kelleghan1, Shane Ward1, Enda Hayes2, Mark Everard2 and Thomas P. Curran1
1UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.
2University of the West England, Bristol, United Kingdom.

Abstract

Agriculture is the primary contributor of atmospheric ammonia in Ireland, where it accounts for 98% of emissions. In order to comply with the Habitats Directive (92/43/EEC), and subsequent devolved National European Communities (Birds and Natural Habitats) Regulations 2011 (SI 477/2011) it is necessary to prove beyond any reasonable doubt that agriculture in Ireland has no significant impact on Natura 2000 (N2K) sites, comprised of Special Areas of Conservation (SAC) and Special Protection Area (SPA). In the absence of Irish specific data on sensitivity of habitats, United Kingdom Critical loads were assigned to every habitat within the Irish network of SACs in this study. Using Geographical Information Systems (GIS) Irish critical load data was superimposed over the ammonia deposition map produced by the Environmental Protection Agency in 2000. GIS was then used to calculate which SAC sites had habitats which exceeded their critical load for ammonia. Taking the total area covered by SACs, 24% were above their critical load and therefore were being impacted by atmospheric ammonia.

Introduction

The Food Harvest 2020 (FH2020) strategy aims to increase Irish primary agricultural production by 33%. Following the increase in total annual national ammonia emissions from 1990 at 107 Gg to the 1998 high of 121 Gg, ammonia emissions had decreased to an 11 year low of 103 Gg by 2011. Considering agriculture accounts for 98% of Ireland’s ammonia emissions, any increase in agricultural activity will lead to an associated increase in atmospheric ammonia emissions, assuming no change occurs in management practices.

The deposition of reactive nitrogen in the form of ammonia poses a significant threat to biodiversity (Sutton et al., 2011). Atmospheric ammonia poses a significant threat to habitats and species accustomed to low nutrient environments, such as bogs, heathlands and sand dunes. The mechanisms of impact on natural habitats and species from increased levels of atmospheric ammonia are numerous: i) outcompeted by nitrophilous plant species; ii) direct toxicity to plants at high levels; iii) eutrophication; iv) acidification; and associated secondary impacts such as the depletion of food resources (lichens) for the Kerry slug (Hicks et al., 2011).

A critical load is the minimum amount of nitrogen needed to illicit a response in the conservation objectives of an N2K site. In many European Union countries such as the Netherlands they have taken the approach of assessing the exceedance of critical loads, this approach has not yet been taken by Ireland (JNCC, 2014).

This study has assigned UK critical loads of ammonia to every Irish Natura 2000 site, which are then screened against modelled ammonia deposition maps of Ireland (EPA, 2000). This is used as a means to identify the most vulnerable sites to atmospheric ammonia. If expansion plans for agriculture under FH2020 are to function within a sustainable environment, it is necessary to classify and evaluate resultant ammonia emissions.

The aim of this study was to identify protected habitats in Ireland which exceeded their critical loads of reactive nitrogen in 1999/2000 in order to screen the most heavily impacted sites.
Materials and Methods

In the UK, the Centre of Ecology and Hydrology (CEH) have developed the Air Pollution Information System (APIS) website (CEH, 2015). This website has site specific details for every Natura 2000 site within the UK. The Critical load for each Irish habitat was extracted from this website. The original SAC boundaries were downloaded from the NPWS mapviewer website (NPWS, 2013).

SAC habitats were given priority within this assessment. UK Nitrogen Critical Loads were assigned to every habitat within the entire suite of Irish SACs. Where multiple habitats were present within an SAC, the most sensitive critical load was applied to the whole SAC. Using GIS the calculated deposition on a 5 km x 5 km grid was subtracted from the critical load assigned to each SAC. Hence, every SAC was mapped based on the most sensitive habitat and the deposition of ammonia in that area.

Results and Discussion

Of the SACs in Ireland, 38% were excluded from this assessment as they were not sensitive to N enrichment, the critical loads were not available on APIS, or were designated solely for animal species, e.g. otter, lesser horseshoe bat. Of the remaining 62% of SACs which could be assessed, 60% fell below its critical load for nitrogen, whereas 40% were above their critical load.

This shows that in 1999/2000 40% of Irish SACs were being negatively impacted by agricultural emissions, long before planned increases under FH2020. The proportions of exceeded critical loads can be seen in figure 1, though 60% of sites are below their critical load, 17% of these were only 1 Kg/ha/yr below. With increases in agricultural activity, there may already have been an increase in the number of sites which exceed their critical load.

![Figure 1](image-url): The proportion of SAC habitats in relation to their critical load exceedance (positive figure means over the critical load).
Figure 2: Special Areas of Conservation (SAC) overlapping the ammonia deposition map. Figure 3: SACs where ammonia deposition exceeds or falls below the critical loads for nitrogen deposition. Figure 4: SACs where ammonia deposition falls below the critical loads for nitrogen deposition. Figure 5: SACs where ammonia deposition exceeds the critical loads for nitrogen deposition.
Conclusion

This project shows that a quarter of Ireland's total SACs exceeded their critical loads in 1999, and even more are at risk of currently exceeding them. As such an updated ammonia deposition map has been created by the EPA in 2015, which will be used in future projects. Though this project used a deposition map from 1999/2000, it acts as a screening tool using the best available scientific evidence; with the new map the GIS dataset can be easily updated. The remaining 37% of Ireland's SAC network, though not identified as being under threat in 1999/2000, are still potentially sensitive receptors to atmospheric ammonia pollution. As Food Harvest 2020 intends to increase all agricultural production by 33% we are likely to see increases in ammonia emissions without abatement strategies in place. When the implementation of these planned increases occur, it is vital that a spatially aware approach is taken where the increases are of significant remove from sensitive Natura 2000 Sites. If agriculture and expansion plans under FH2020 are to function within a sustainable environment, it is necessary to classify and evaluate resultant ammonia emissions; thus complying with the Habitats Directive (92/43/EEC), and subsequent devolved National European Communities (Birds and Natural Habitats) Regulations 2011 (SI 477/2011).

Acknowledgements

The authors acknowledge funding for this project by STRIVE as administered by the Environmental Protection Agency. The authors would also like to thank both the EPA and the National Parks and Wildlife Service for information and support provided. Further details of the project are available at http://ssu.ie/research/ammonian2k/ and on our twitter page https://twitter.com/AmmoniaN2K/.

References


Livestock excreta accounts for more than 80% of Ammonia (NH₃) emissions from European agriculture. There is, however, a wide variation among countries in emissions from the main livestock sectors: cattle, sheep, pigs and poultry. This variation between countries is explained by the different proportions of each livestock class (and their respective N excretion and emissions), by differences in agricultural practices such as housing and manure management, and by differences in climate. The aim of this project was to compare the potential impact of ammonia emission from livestock on mainland Spain and in the Republic of Ireland. The United Kingdom’s Environment Agency threshold distances (1 km, 5 km, 10 km and 15 km) were adopted, to identify priority areas for assessment within the Natura 2000 Network (N2K sites) of intensive agriculture.

Introduction

Typically, more than half of the N excreted by mammalian livestock is in their urine, between 65 and 85% of which is in the form of urea and other readily-mineralized compounds. Urea is rapidly hydrolyzed by the enzyme urease to (NH₄)₂CO₃ and (NH₄⁺) ions, which provide the main source of NH₃ (EEA, 2013). Nitrogen deposition is a particular problem for the N2K sites which has been established by the Habitats Directive (92/43/EEC). Subsequent devolved National European Communities (Birds and Natural Habitats) Regulations 2011 (SI 477/2011) in Ireland (IE) and the Natural Heritage and Biodiversity Legislation 2007 (Act 42/2007) (including amendments 04/11/2014) in Spain (ES). This is intended to protect Europe’s most valuable and threatened species and habitats (Hicks et al., 2011).

As the majority of the N2K Network and agricultural sources are within a rural setting, there is potential for widespread effects of NH₃. By 2020, 64% of the Natura ecosystem areas across the EU will be at risk from excessive nutrient N deposition (Hicks et al., 2011). NH₃ emissions for IE in 2010 were 105 kt while ES was 343 kt. In the EU, only ES (+ 15%) and Cyprus (+ 0.1%) reported increased NH₃ emissions from 1990 to 2010, IE showed a reduction of 1.8%. One reason for the large increase in NH₃ emissions observed in ES is due to increased numbers of cattle, swine and poultry (Eurostat, 2014).

In 2010, IE and ES were 7% and 19% below their respective emissions ceilings, as set out by the National Emissions Ceilings Directive (NECD) (2001/81/EC). Excluding the biological impact of NH₃ emissions, there are many other disadvantages from intensive livestock, such as the production of other greenhouse gases and potential for ground water contamination (Tilman et al., 2002).

The objective of this study was to compare intensive pig and poultry units within the threshold distances 1 km, 5 km, 10 km and 15 km in order to screen N2K sites against intensive agriculture in Ireland and Spain.
Materials and Methods

From the websites of the PRTR-España (2014) and EPA (2014) facility inventory data of units for the intensive rearing of poultry with 40,000 places; 2,000 places for pigs over 30 kg and 750 places for sows were obtained. These units require licensing under the IPPC (Integrated Pollution Prevention and Control Directive) (2008/01/EC), these data were used to generate point shapefiles in ArcMap 10.3. N2K site boundary shapefiles were downloaded from the European Environment Agency (EEA) website (EEA, NA). ArcMap 10.3 was used to generate “buffers” around the intensive units using the adopted UK Environment Agency threshold distance for 1, 5, 10 and 15 km. These were mapped as priority areas for consideration of impact arising from atmospheric NH₃. It was possible to extract the N2K sites which fell within range of the threshold distances for 1, 5, 10 and 15 km for NH₃. Emissions from each agricultural sector were obtained from EEA (2011); these are presented in Figure 3.

Results and Discussion

The total NH₃ emissions from agriculture (IE and ES) are 107 kt and 348 kt respectively. In IE and ES 74.77% and 32.64% of NH₃ emissions, respectively, were from livestock buildings. They were dominated by cows in IE and pigs in ES with the percentage of NH₃ emissions of pig and poultry units being 7.42% and 2.65% in IE while in ES they were 6.45% and 17.77%, respectively (Figure 3). The area of the full N2K network of both countries was calculated based on the actual area covered which excludes any overlap of Special Areas of Conservation (SAC) and Special Protection Areas (SPA) (Table 1), the percentage designated by N2K sites is almost 6% more in ES than in IE.

Figure 1: Priority N2K areas for assessment, showing N2K sites as they appear within 1 km, 5 km, 10 km, and 15 km in ES.
Table 1: Summary of N2K coverage within UK Environment Agency distance thresholds of intensive agriculture units (pig and poultry), and the total coverage site from IE and ES.

<table>
<thead>
<tr>
<th>EA Distance Threshold</th>
<th>% Total N2K</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPAIN</strong></td>
<td></td>
</tr>
<tr>
<td>1 km</td>
<td>0.44</td>
</tr>
<tr>
<td>5 km</td>
<td>9.43</td>
</tr>
<tr>
<td>10 km</td>
<td>18.76</td>
</tr>
<tr>
<td>15 km</td>
<td>17.38</td>
</tr>
<tr>
<td>% of ES Designated as N2K</td>
<td>28.36</td>
</tr>
<tr>
<td><strong>IRELAND</strong></td>
<td></td>
</tr>
<tr>
<td>1 km</td>
<td>0.08</td>
</tr>
<tr>
<td>5 km</td>
<td>2.78</td>
</tr>
<tr>
<td>10 km</td>
<td>6.17</td>
</tr>
<tr>
<td>15 km</td>
<td>6.97</td>
</tr>
<tr>
<td>% of Ireland Designated as N2K</td>
<td>22.98</td>
</tr>
</tbody>
</table>

Of the total area covered by the N2K sites, 0.08% and 0.44% falls within 1 km of pig and poultry units in IE and ES, respectively. The concentration of pig and poultry units within 1 km of N2K sites is five times higher in ES than in IE (Figure 1 and Figure 2). The concentration of pig and poultry units within 5, 10 or 15 km is two to three times in ES than in IE (Table 1). As ES has more of its land covered by N2K sites, it is more likely to overlap with “buffers” around pig and poultry houses. However, before any impact can be predicted the impact of the emissions from the source will need to be cross referenced with the Critical Loads and the Critical Levels of designated features that lie within the priority N2K areas.

Figure 2: Priority N2K areas for assessment, showing N2K sites as they appear within 1 km, 5 km, 10 km, and 15 km in IE.

Figure 3: NH₃ Emissions from Irish and Spanish intensive agriculture units (EEA, 2011).
Recognition needs to be given concerning the diversity of N2K sites when viewing the areas identified in Figure 1 and Figure 2. As N2K sites with differing climates will have varying levels of sensitivity to atmospheric NH$_3$ (MAGRAMA, 2014). The NECD covers four main air pollutants including NH$_3$; these can cause respiratory problems, contribute to the acidification of soil, surface water and damage vegetation (EEA, 2014). Following analysis of the population sizes of ES and IE, it was noted that agricultural ammonia emissions were 7.48 kg/person for ES, and 23.29 kg/person for IE.

Conclusions

Intensive agriculture is a primary source of atmospheric NH$_3$; the 2010 NH$_3$ emissions of pig and poultry are 7.42% and 2.65% for IE and 17.77 and 6.45% for ES, respectively. This screening carried out in this project serves to highlight the potential risk areas where further assessment is required; it does not identify the most heavily impacted areas of either IE or ES. N2K sites are an integral part of the countryside, it is important that the sites be monitored in a way that takes into account the vulnerable habitats and species present.

Acknowledgements

The authors acknowledge funding for this project by STRIVE as administered by the Environmental Protection Agency. The authors would also like to thank both the EPA and the Spanish Register of Emissions and Pollutant Sources (PRTR-España) staff for information and support provided. Further details of the project are available at http://ssu.ie/research/ammonian2k/ and https://twitter.com/AmmoniaN2K.

References


European Communities (Birds and Natural Habitats) Regulations 2011, S.I. No. 477/2011


(Natural Heritage and Biodiversity) Legislation 2007, Act 42/2007


SENSTIVITY OF IRISH GRASSLANDS TO ATMOSPHERIC NITROGEN FROM INTENSIVE PIG AND POULTRY FARMS

Charles De Wulf, David Kelleghan, Thomas P. Curran
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Agriculture in Ireland is responsible for the majority of national atmospheric ammonia (NH₃) emissions, the deposition of which causes acidification and eutrophication of ecosystems. Biomonitoring techniques such as vascular plants, bryophytes and lichens have been used to indicate potential ecological impacts as they arise from atmospheric Nitrogen. Moss cover and N-Ellenberg values were used in this study to assess both their suitability as biomonitoring tools, and the potential sensitivity of Irish grasslands to pig and poultry farms. When compared to cattle farming, intensive agriculture is expected to have much lower albeit more concentrated emissions, this in theory should result in ecological impacts close to farms and reducing along a gradient.

Introduction

Ammonia can have numerous adverse impacts on the environment. When deposited, it plays a crucial role in the acidification of soils and in the eutrophication of ecosystems, therefore affecting many sensitive species and habitats (Hicks et al., 2011). As the largest sources of ammonia are domestic animals and fertilizers, it has been estimated that agriculture in Ireland is responsible of about 95% of national anthropogenic emissions (Philippe et al., 2011). As a result, the expected increase in the level of production by at least 33% in order to reach goals of Food Harvest 2020 is likely to be correlated with an increase in ammonia emissions. Any existing impacts on the environment will subsequently be reinforced. However, the “twin challenge” of productivity and sustainability currently faced in Ireland supposes that these production goals have to be achieved while at the same time complying with EU environmental targets. As pig and poultry production are concentrated sources of ammonia (unlike cattle as a diffuse source) they are primary targets for the assessment of atmospheric Nitrogen impacts on ecosystems.

The use of biomonitoring is an approach which could provide an early warning for sites of nitrogen sensitivity. Plant species compositions carry information about the changes in environmental conditions in which they grow and can therefore serve as indicators of key environmental factors (Schröder et al., 2010). The Ellenberg Nitrogen Index (which is a general indicator of soil fertility) requires the allocation of an N score to each plant species so that the overall mean score for the community lies on a nutrient richness scale. Mosses, which are good at absorbing nitrogen and quickly deteriorate if they get overloaded, can also be used as a Nitrogen sensitivity indicator. Employment of existing recorded data is consequently deemed to be an efficient method to provide assessments of national level impacts. As part of this study, the NPWS Irish semi-natural grasslands survey 2007-2012 provided a comprehensive botanical dataset covering 23,188.1 ha across Irish grasslands.

The objective of this study was to assess relevés collected as part of the NPWS Irish Grassland Survey for sensitivity to Nitrogen. These data were then used to investigate any potential spatial patterns of nitrogen sensitivity when compared to locations of intensive pig and poultry installations in Ireland.
Material and Methods

This study utilized the NPWS Irish semi-natural grasslands survey (ISGS) 2007-2012 data, which contains a comprehensive list of vascular plant species and their relative abundance (Domin scale) for 4632 relevés (O’Neill et al., 2013). Applying N Ellenberg indicator values adapted for British plants (Hill et al., 1999) to every species when available\(^1\), then allowed for the calculation of an N-Ellenberg mean to each relevé. The proportion occupied by individual species was taken into account, rather than relying solely on their presence/absence. In addition to a range of other parameters recorded in the ISGS, moss cover was also analyzed as part of this project. Due primarily to bryophytes noted sensitivity to nitrogen, mosses were used as a second biomonitor. Both these indicators were employed to generate point location shapefiles in ArcMap 10.3 (Figure 1). ArcMap was then used to calculate the mean values for both biomonitor on a 10 km grid. The adopted UK Environment Agency threshold distance of 1, 5, 10 and 15 km allowed the generation of buffers around IPPC licenced (2008/01/EC) pig and poultry farms. These were then used to calculate the mean for N-Ellenberg and moss cover biomonitor using the point locations which fell within these distance thresholds.

Results and Discussion

The average N-Ellenberg mean among these sites is 4.06, with a standard deviation of 0.52. N-Ellenberg means are mainly comprised in a narrow scale, as 93% of them range from 3 to 5. Moss cover, which has more evenly distributed values across its range, with a mean of 3.85 and a standard deviation of 2.02.

![Figure 1](image)

**Figure 1**: Assessment of Irish grasslands sensitivity to Nitrogen with both N-Ellenberg mean (a) and moss cover (b) biomonitor, with a 15km buffer around pig and poultry houses.

\(^1\)The species for which no N-Ellenberg value was available were removed from the relevés in order to calculate their Ellenberg mean.
Table 1: Proportion of total samples of N-Ellenberg mean (a) and Moss Cover (b) which were taken up by each class.

<table>
<thead>
<tr>
<th>Class</th>
<th>N-Ellenberg Mean (a) Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 – 3</td>
<td>2.27%</td>
</tr>
<tr>
<td>3 – 4</td>
<td>44.50%</td>
</tr>
<tr>
<td>4 – 5</td>
<td>48.69%</td>
</tr>
<tr>
<td>5 – 6</td>
<td>4.19%</td>
</tr>
<tr>
<td>6 – 7</td>
<td>0.35%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Class</th>
<th>Moss Cover (b) Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 2</td>
<td>20.26%</td>
</tr>
<tr>
<td>2 – 4</td>
<td>33.15%</td>
</tr>
<tr>
<td>4 – 6</td>
<td>29.65%</td>
</tr>
<tr>
<td>6 – 8</td>
<td>13.26%</td>
</tr>
<tr>
<td>8 – 10</td>
<td>3.68%</td>
</tr>
</tbody>
</table>

According to N-Ellenberg mean indicator, the majority of Irish grasslands are made up of low to intermediate fertility sites (i.e ranging from 3 to 5), which translates into a relatively low sensitivity to Nitrogen. Contrariwise, as the distribution of moss cover is more widely spread into the different classes, this may hence suggest its use as a more suitable indicator of atmospheric nitrogen. While vascular plants source the majority of their nutrients into the soil, lower plants such as lichens and mosses depend on atmospheric inputs as their primary source of nutrients (Boltersdorf et al., 2014). Because of their specific physiology and ecology, mosses are deemed to be more suitable to indicate atmospheric N input at ecosystem level.

Of the relevés 42% fell into the 15km buffers around intensive pig and poultry farms (Figure 1). Within these buffers, an average upward trend in moss cover is observed as the distance from farms increases, whereas the N-Ellenberg mean remains static (see Figure 2). Although a high standard deviation remains for moss cover, its noticeable spatial pattern tends to indicate a potential ecological impact of Nitrogen emissions around intensive units. Both the substantial increased in atmospheric ammonia concentrations and the detection of ammonia characteristic injury symptoms on bryophytes close to farms observed in a previous study in Northern Ireland (Sutton et al., 2011) support this theory. This further implies that moss cover may be a more suitable indicator of existing Nitrogenous impacts on the environment.

![Figure 2](image-url): Spatial pattern of ammonia sensitivity around pig and poultry intensive units with both N-Ellenberg mean (a) and moss cover (b) indicators

By contrast to methods which are source-oriented, ecological assessment through biomonitors are receptor-oriented and have therefore only an indirect connection to the pollution source (Sutton et al., 2011). As other factors may also affect the biomonitors, the influence of soil and habitat types (these factors had been recorded for each relevé) were statistically tested on the relevés which fell into the 15 km buffers around pig and poultry farms. Given that the variation between the different classes of soil and habitat were lower than the variation between each class itself, these factors (i.e. habitat and soil types) seemed not to have any observable influence.
Conclusion

As mosses are noted as being sensitive to Nitrogen, they are likely to be a more suitable biomonitor when compared to N-Ellenberg values. Using moss cover data from NPWS Irish semi-natural grasslands survey identified possible ecological impacts around pig and poultry farms. As this study relied on means of both moss cover and N-Ellenberg value for each relevé, the highly unequal spatial distribution of relevés may have played a role in the difficulty detecting changes in the N-Ellenberg values and the high standard deviation in moss cover. Depending on the location of the pig or poultry farm, it may have had a higher or lower number of proximal relevés, for example Wicklow had 13 relevés whereas Cork had 600. In addition, N-Ellenberg values could only be applied to 54% species recorded in the NPWS ISGS, the exclusion of the remaining 46% of species may also potentially impact the N-Ellenberg mean. The inclusion of more datasets available from NPWS could allow to further investigate these spatial patterns on a national level, whereas counties with comparable numbers of relevés may be assessed independently. Further assessment could also lead to the identification of priority areas within the N2K network which are potentially exposed to excess ammonia levels and loads.

Acknowledgments

The authors acknowledge funding for this project by STRIVE as administered by the Environmental Protection Agency. The authors would also like to thank both National Parks and Wildlife Service and the National Biodiversity Data Centre for information and support provided. Further details of the project are available at http://ssu.ie/research/ammonian2k/ and https://twitter.com/AmmoniaN2K.

References

HUMAN HEALTH RISK ASSESSMENT OF LEAD FOUND IN TAP WATER IN IRELAND

Andrena Meegan and Enda Cummins
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Universal access to safe drinking water is a global challenge with many governments putting in place regulations to ensure a safe drinking water supply. Within Ireland, in recent years a great interest has been aroused in the quality of water. The emerging pollutant of lead found in many water supplies within Ireland has caused increased concern. The aim of this paper is to evaluate the risk of lead, (a chemical hazard) to the human health population of Ireland. A quantitative risk assessment using Monte Carlo simulation will be developed with a framework model presented in this paper.

Introduction

The core principle of the EPA’s regulation of drinking water supplies is to ensure supplies are “safe” and “secure.” Within Ireland there are many regulations relating to the quality of drinking water. The EPA strives to ensure all tap water reaching homes and businesses is safe to consume. The quality of water from public mains is usually high and compliant with EU drinking water standards however poor water quality in certain parts of Ireland continue to challenge authorities responsible for drinking water. Water sources are abundant in Ireland with the majority of water originating from surface water (81.9%) and the reminder originating from groundwater (10.3%) and springs (7.8%) (EU, 2007). In the past there has been a rise in the number of public water supplies where lead is found in large quantities however lead is generally not found in water leaving the drinking water treatment plant (EPA, 2009). In the majority of cases, it was found lead pipes and plumbing were still in place and therefore causing leaching into the water system. Studies have shown houses built before the mid 1970s contain lead pipes inside the house and also outside where the water is supplied to the house (EPA, 2014). Lead (Pb) is a heavy metal which is highly toxic to humans especially children. Lead poisoning is one of the most common and recognized childhood diseases of toxic environmental origin (WHO, 2010). Both children and adults can be exposed to lead from multiple sources however since the 1990s when lead was banned as a component in petrol and paint in Europe, drinking water has become one of the main contributors to lead intake. Lead can cause numerous health effects to young children, babies and infants in the womb such as brain development causing problems with learning, behaviour and attention (EPA, 2014). Lead poisoning in adults can cause kidney problems and has been associated with high blood pressure and cancer. Once lead is consumed by drinking water, it enters the blood stream and due to its high toxicity leads to lead poisoning. The authorities have recognised the dangers of lead and in December 2013 reduced the legal limit of lead in water from 25mg/L to 10mg/L (EPA, 2013). This is to try and reduce everybody’s lifetime exposure to lead. Within Ireland the authorities have made plans to change all lead pipes carrying water to homes and businesses to help reduce the exposure to lead however this is a slow process and many places in Ireland do not have access to safe water still today.

The objective of this study is to determine if Lead (Pb) poisoning from tap water in Ireland is a major risk to human health using quantitative risk assessment.
Materials and Methods

Water Sampling

The objective of the study will be achieved by conducting tests on samples of water taken from three different sources of tap water within Ireland. Samples of water will be taken from three different locations; Limerick, Clare and Armagh. Both Limerick and Clare are known as areas of risk relating to lead pollution in water. Armagh is considered an area of low risk relating to lead pollution. The results from the sampling will be run through a quantitative risk assessment with Monte Carlo simulation modelling to determine the results.

Contaminant test

A spectrophotometer will be used in this study to analyse the content of lead in the water samples. The samples will undergo a fast test of standard comparable analysis. The Hach Lange test will be used to determine levels of lead between 0.1-2.0mg/L and the result is for total lead digestion using CRACK SET LCW902.

Framework Model

A model structure for flows of tap water and human health effects should be established in order to construct a quantitative risk assessment. This study examines the main reasons for lead entering tap water and the whole treatment of water will be taken into account.

Figure 1: A framework model of water treatment processes until consumption
Figure 1 represents the whole process of water treatment from primary until it reaches the taps of homes and businesses. The main cause for lead in tap water is through pipes and plumbing so this will be a main focus in developing a risk assessment model for the study. This model provides a guideline of the processes which water undergoes before human consumption. This will allow the probability of water contaminated by lead in each step to be outlined in the risk assessment.

Quantitative Risk Assessment

In this section, the probability of occurrence of lead in water and water consumption will be taken into account it will also take into account final exposure levels of consumers and will allow the evaluation of the risk to consumers being exposed to lead. Monte Carlo simulation will be used in this study based on the framework model found in Figure 1. In this study, lead hazard exposure levels will be calculated based on the equation below

\[ E = L \times C \]

Where:
- \( E \) lead exposure levels (µg for lead)
- \( L \) lead initial levels in tap water (µg for lead)
- \( C \) likely water consumption (l)

Lead will be measured using the units µg/l in the water samples collected. The lead content found in tap water and the likely water consumption will be inputs and the exposure levels considered the simulated output. Further study will be done using previous publications to develop the model and the risk assessment.

Results

Regulation set in place by the EPA for drinking water quality have reduced the amount of lead acceptable in December 2013 from 25 mg/L to 10 mg/L. However reports from EPA (2014) have stated no levels of lead in drinking water are considered safe. Drinking water above the recommend level should have methods set in place to reduce lead content for the public’s safety.

In 2013, within Ireland the authorities reported 11 exceedances of the 25 mg/L limit and out of 46 samples taken 33 were well above the new limit of 10 mg/L (EPA, 2014). The results from the levels of lead in samples taken for this study will show if any improvements have been made in drinking water quality concerning lead.

The data required for the risk assessment model will need further study and research. The data collected will be assessed and presented using the Monte Carlo stimulations model.

Conclusion

Providing people with safe drinking water is a human need of universal relevance. Ensuring drinking water is of the highest quality is vital for public health, our food industry, tourism and future
generations. This can be improved using risk assessment to determine major causes and impacts. Qualitative risk assessment has emerged as the predominant paradigm for describing public health consequences of human exposure to contaminants and further study on this risk assessment can provide guidance and help ensure public drinking water is safe to consume.

References


AN ANALYSIS OF THE TRENDS IN IRISH PRECIPITATION PATTERNS

Juan Vinagre-Sendino and Patrick Grace
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract
Whatever approach is considered, the fact that the climate is changing is real. Precipitation is one of the main factors that allows the appreciation of this change. Ireland’s rainfall increase could become the main element in making much of the land waterlogged and useless for common activities such as agriculture or building construction. For this reason, as a preliminary step to considering an effective drainage system, a thorough statistical analysis has been performed in order to know if the Irish precipitation trends call for such an investment.

Introduction
Climate change refers to any perturbation or evolution that a climate system has experienced with respect to time (Ahrens 2007). There are different points of view on this phenomenon. Some say that it is produced by anthropogenic activities such as the massive burning of fossil fuels which considerably increases the amount of greenhouse gases in the atmosphere and directly stimulates global warming. Others believe that climate change is a natural process that is determined by the interruption to the balance of a complex system formed by the atmosphere, the biosphere, the lithosphere and the hydrosphere. For example, according to Milancovitch’s theory, little variations in the Earth’s orbit and relative position with respect to the sun directly affect the sunlight reaching its crust. This can explain the glacial and interglacial cycles (Cowie 2013). Among all the parameters that define the weather and, consequently, the climate, such as temperature, cloudiness, wind, humidity and precipitation, this project has only focused on precipitation, studying its changes over time for the particular case of Ireland. Investigations show that the impact of global climate change on Irish precipitation leads one to accept that the rainfall average is increasing. Nevertheless, such research also considers the difficulties in establishing clear patterns of this tendency due to the great variability of rainfall during the different seasons and to the different amounts of rainfall in the Irish regions (McGrath and Lynch 2008).

During the last century, increases in annual rainfall of up to 300 mm have been observed in some places. In general, this rainfall average decreases from West to East across the island generating uncertainty about the real changes in the precipitation patterns (Dwyer 2012). According to the Irish Meteorological Service, the differences in rainfall averages throughout the country are so big, that they can show a completely different scenario. Thus, while in most of the Eastern half of the island, the yearly rainfall oscillates between 750 and 1000 mm, in the West of the country it oscillates between 1000 and 1400 mm. The number of rainy days during a year in the East is significantly lower than in the West. This peculiarity is highly influenced by the topography which makes the uplands of the West have up to 50% more annual rainfall than the adjoining lowlands. This precipitation is generated by the Atlantic winds that are forced to an upward movement when they encounter the geomorphology of the upland of the West (Met Éireann 2015). This “local effect” on the rainfall pattern in Ireland has to be taken into consideration when analysing the precipitation data of the whole country, not only because of its influence when deducting a long term tendency, but also because of the extreme differences in rainfall between places. The trend should be more evident in places where the rainfall is more abundant.

The objective of this project is to perform a statistical analysis of the Irish precipitation in order to establish its trend.
Materials and Methods
In this project, different points of view have been taken into account in order to analyse the trends in the Irish precipitation. Firstly, the analysis was conducted taking the different months of the year which are affected by important precipitation differences. To investigate this, a sample of the monthly rainfall average in millimetres since 1900 has been taken. These data have been collected by the World Bank and have been obtained from the web site of this organization. The monthly data was divided into four periods over the last century: 1900-1930, 1930-1960, 1960-1990 and 1990-2009, respectively. In order to know if the means of the four groups are significantly different, the parametric One-way ANOVA test (analysis of variance) and the nonparametric Kruskal-Wallis test have been carried out using the PASW.18 statistic software.

It is necessary to consider that using monthly rainfall data implies a great variability due to the big differences in rainfall patterns in Ireland between the summer and the winter time. If the year is divided into two periods: one with the months of higher rainfall and the other with the months of lower precipitation, figure 1 is obtained (see below). As it can be observed in the graphic, the average rainfall during the “wet” months of the year (from September to February) has been steadily increasing during the four periods of the last century. The mean of each period is higher than the precedent. This circumstance reflects that the rainfall average is increasing, thus suggesting an upward tendency. On the contrary, the average rainfall during the “dry” months of the year (from March to August) is much lower, and no clear trend can be observed in it.

![Figure 1. Rainfall average in two periods of the year](image)

Secondly, it is important to analyse the rainfall pattern without considering the monthly variability and the location effect, with this aim a time series of the annual average rainfall in Ireland since 1941 to 2012 has been taken. To analyse if the changes in precipitation during the period are statistically significant, the data has been divided into two groups of equal size: one from 1941 to 1976 and the other from 1977 to 2012. To know if the difference between the means of both groups is significant, a parametric t-test and a nonparametric bootstrap test have been carried out using the the PASW.18 statistic software.

Results and Discussion

Monthly rainfall trend analysis with One-way ANOVA and Kruskal-Wallis tests
The results of the analysis are in the following table 1. In this test, the total variation is divided into two components. Between groups reflects variation of the group means around the overall mean. Within groups reflects variation of the individual scores around their respective group means. Sig indicates the significance level of the F test; in this case 0.723 is a value higher than 0.05, indicating that there are no differences among the four period.
Table 1. One-way ANOVA results for rainfall

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>590.018</td>
<td>3</td>
<td>19.673</td>
<td>0.444</td>
<td>0.723</td>
</tr>
<tr>
<td>Within Groups</td>
<td>19500.878</td>
<td>44</td>
<td>443.202</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>20090.897</td>
<td>47</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To confirm the results obtained with the ANOVA method, the Kruskal-Wallis test, which is a nonparametric alternative where the scores are ranked regardless of group membership, has been used. The Kruskal-Wallis test compares the medians of the four groups of data to see if they are different (Sheskin 2004).

Table 2. Kruskal-Wallis results

<table>
<thead>
<tr>
<th></th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-Square</td>
<td>1.508</td>
</tr>
<tr>
<td>df</td>
<td>3</td>
</tr>
<tr>
<td>Asymp. Sig.</td>
<td>0.680</td>
</tr>
</tbody>
</table>

The results obtained using the Kruskal-Wallis nonparametric test are shown in table 2 where a significance of 0.680 is determined. This value is higher than 0.05 indicating that the group locations do not differ. This result is coherent with the ANOVA test and leads one to consider that the differences in the average monthly rainfall during the four periods selected in the last century are not statistically significant.

Annual rainfall trend analysis with t-test and Bootstrap.
The statistics obtained for each group of data stated above show that the means differ. The annual rainfall mean for the period of 1941 to 1976 is 1176.4 mm while the mean for the period of 1977 to 2012 is higher, 1256.0 mm. To know if this difference is significant, a t-test for equality of means has been performed (Pfafflin and Ziegler 2006).

Table 3. t-test results

<table>
<thead>
<tr>
<th></th>
<th>Levene Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
<td>t</td>
</tr>
<tr>
<td>Rainfall</td>
<td>0.222</td>
<td>0.639</td>
<td>-2.896</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The significance value for the Levene test is more than 0.05, which means equal variances for both groups can be assumed. The significance value for the t-test is also less than 0.05, indicating that there is significant difference between the rainfall means. Zero value is not contained in the confidence interval for the mean difference; this reflects that the difference is significant. The classical procedures of the t-test for comparing two groups are restricted by the assumptions of normality and equal variances.
Even though the Levene test performed above has led to accept the equality of variances, a bootstrap test has been used to compare the means of the groups of rainfall data. With this test the effect of possible violations of these assumptions can be avoided. To carry out the bootstrap test, the datasets were resampled with replacement for 1000 times, obtaining the following group statistics.

Table 4. Bootstrap results

<table>
<thead>
<tr>
<th></th>
<th>Bootstrap</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Bias</td>
<td>Std. Error</td>
<td>Sig. (2-tailed)</td>
</tr>
<tr>
<td>Rainfall</td>
<td>difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td>79.5833</td>
<td>0.4751</td>
<td>28.02413</td>
<td>0.007</td>
</tr>
<tr>
<td>Equal variances not</td>
<td>79.5833</td>
<td>0.4751</td>
<td>28.02413</td>
<td>0.007</td>
</tr>
</tbody>
</table>

The output shows the results of the bootstrapping procedure. The standard error of the mean difference is 28.02 instead of the 27.48 obtained with the t-test. The difference between means is -79.58, and the confidence interval goes from -133 to -24.9. This interval implies that the difference between means in the population is negative. This bootstrap confidence interval confirms the conclusion obtained with the parametric t-test. Therefore, it can be assumed that the rainfall annual average in Ireland in the period 1977-2012 has been significantly higher than in the preceding period, 1941-1976.

Conclusions

From the results of the analysis of the rainfall pattern in Ireland which has been carried out, it can be concluded that, in an overall context for the country, there is evidence that the average precipitation is increasing over time. Nevertheless, since this trend is influenced by location and seasonal factors, it can be said that it is not uniform, in fact, in the “dry” places of the island, no increase could be observed. These particularities should be taken into consideration when deciding to implement a drainage system, a situation where a cost-benefit analysis could be determined.

References


DEVELOPMENT OF A NATIONAL STRATEGY FOR RECOVERY AND UTILISATION OF FAT, OIL AND GREASE (FOG) WASTE FROM FOOD SERVICE OUTLETS (FSOs)

Thomas Wallace¹, Michael O’Dwyer² and Thomas P. Curran¹
¹UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.
²Evolution Environmental Services Ltd in partnership with Noonan Services Group, The Guinness Enterprise Centre, 8 Taylor’s Lane, Dublin 8, Ireland.

Abstract

Fat, oil and grease (FOG) is a waste by-product of food production. It is produced on both a domestic and commercial level. If it enters sewers, it accumulates causing blockages and sanitary system overflows (SSOs); the cost of clearing these can be significant. To prevent FOG waste from entering sewers, source control may be implemented by food service outlets (FSOs) by installing grease trapping systems (GTSs). Used cooking oil (UCO) and grease trap waste (GTW), retained in the GTSs, from FSOs must be utilised efficiently. Currently, FOG waste is collected by permitted waste hauliers for land application, landfilling, composting, incineration, anaerobic co-digestion or biodiesel production. This paper is a brief outline of the proposed life cycle assessment to be carried out on the FOG waste produced by FSOs in Ireland. International methods currently in use will be analysed to determine if the integration into Ireland’s system is feasible. GIS mapping will be integrated to determine the most cost efficient and carbon neutral FOG utilisation sites for Ireland’s core urban centres.

Introduction

Fat, oil and grease (FOG) waste is a growing environmental concern. Increased urbanisation of populations and the change in people’s eating habits over the years with increased attendance at restaurants have contributed to a surge in blockages and sewer overflows due to FOG deposition in the sewers. FOG deposition can also cause corrosion of sewer lines under anaerobic conditions, reducing the lifetime of the pipes (Hussain et al. 2014). In international studies, it is estimated that 50% of sanitary system overflows (SSOs) are caused by FOG build up (Southerland 2002).

In 2008, Dublin City Council (DCC) led the way internationally with the introduction of its innovative FOG programme. All food service outlets (FSOs) (over 2000 in total, from cafes to hospitals) were required to apply for a Trade Effluent Discharge Licence. This licence required FSOs to install adequate grease trapping systems (GTSs) to prevent FOG entering the drainage network and to maintain the GTSs correctly. All FOG waste has to be collected by permitted hauliers. This programme has greatly contributed in reducing FOG blockages in the drainage network. Due to the increase in properly maintained GTSs and improved education of stakeholders, there has been an increase in FOG waste diverted from the drains. Preventing FOG waste from entering the drains is the first step in an efficient FOG management programme. The FOG waste disposal routes must be studied to determine the potential it has as a resource.

International studies show FOG waste has high energy potential. The addition of grease trap waste when digesting sewage sludge increases the methane potential and methane yield during anaerobic co-digestion (Davidsson et al 2008). Waste oil is a viable feedstock for the production of biodiesel. These options reduce the reliance on fossil fuels, reducing emission of greenhouse gases and contributing to reaching renewable energy levels as set out in the EU 20-20-20 policy. More recent studies have shown UCOs potential as a substrate for bio-polymers (non-toxic, biodegradable plastics) which could replace plastics from petrochemical sources in many applications (Ruiz et al 2014).

The objective of this project is to integrate the resource data with GIS to evaluate the energy and revenue opportunities present in the management of FOG waste in Ireland.
Materials and Methods

Categorisation of FOG Waste

Studies refer to FOG as grease trap waste (GTW) or even more specifically the top floatable layer of wastewater rich in lipids in the grease trap (Long et al. 2012). FOG waste and GTW are interchangeable terms in some studies. For the purpose of this study FOG waste refers to all fat, oil and grease produced by FSOs. Under FOG there are two waste streams produced in FSOs. These are used cooking oil (UCO) and grease trap waste (GTW).

Used cooking oil (UCO) or waste cooking oil is fresh cooking oil (originated from vegetable oil or animal fat) after it has been used in cooking processes, primarily the cooking of food in deep fat fryers. It can also be the run off from chicken/duck rotisserie ovens but it is often much thicker in density in this case. UCO is categorised under the 20-01-25 European Waste Category (EWC) code (See Table 1) (EPA 2002). FSOs are required to have UCO collected by permitted waste hauliers, often for use in biodiesel production. Although fresh cooking oil can be used as a feedstock for biodiesel production, its use is greatly criticised as it is the production of a fuel at the expense of a food source. Food vs fuel is an international debate. The use of UCO as a biodiesel feedstock avoids this criticism as the UCO can no longer be used as a food source (Yaakob et al. 2013). UCO contains impurities not present in fresh oil such as free fatty acids and water but once it is treated, studies have shown that it can act as a cheaper option for biodiesel feedstock than fresh oil (Yaakob et al. 2013) as it is utilising a waste stream.

Table 1. FOG categorisation in European Waste Catalogue and Hazardous Waste List

<table>
<thead>
<tr>
<th>EWC (European Waste Catalogue) Code</th>
<th>Description of Waste</th>
<th>Category of FOG</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-01-25</td>
<td>Municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions: Edible oil and fat</td>
<td>Used Cooking Oil</td>
</tr>
<tr>
<td>20-01-08</td>
<td>Municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions: Biodegradable kitchen &amp; canteen waste</td>
<td>Grease Trap Waste</td>
</tr>
<tr>
<td>19-08-09</td>
<td>Wastes from waste management facilities, off-site waste water treatment plants and the preparation of water intended for human consumption and water for industrial use: Grease and oil mixture from oil/waste separation containing only edible oil and fats</td>
<td>Grease Trap Waste</td>
</tr>
</tbody>
</table>

The second category of FOG waste is the waste removed from grease traps in FSOs. This grease trap waste (GTW) includes the entire contents of the grease trap (primarily categorised as EWC Code 19-08-09 (See Table1)) (EPA 2002). GTW has a higher water content and more contaminants than UCO so it is a less suitable feedstock for biodiesel. It is a viable feedstock for anaerobic co-digestion when its moisture content is reduced, increasing biogas yield due to its high calorific value. There are two main types of grease traps in the market. There are passive grease traps (sometimes referred to as grease interceptors when they exceed 1000 L capacity but in this study all sizes will be referred to as passive grease traps) which work through gravitational separation. The passive grease trap is a baffled tank designed to retain the grease trap waste and allow the treated water to enter the sewer system (Wang et al. 2013). The effluent from FSOs washing applications enter the grease trap and the grease settles on top as grease is less dense then water and solid particles settle on the bottom with a wastewater layer between them. In Ireland, all passive grease traps must be sized in accordance with I.S. EN 1825-1, 2004 - Grease Separators-Part 1: Principles of design, performance and testing, marking and quality control and I.S. EN 1825-2, 2002, Grease Separators-Part 2: Selection of nominal size, installation, operation and maintenance.
The second type of grease trap is the automatic grease trap or grease removal unit (GRU). This is smaller in size and often located under sink. The GRUs retain the grease but remove it daily as they are mechanised and often heat the contents of the GRU. They then skim the top layer of FOG into a receptacle which is then stored by FSO staff. These units require daily cleaning and they usually have food filters to catch larger food particles. Similar to the passive grease traps they must be pumped out regularly by permitted hauliers.

Data acquisition
Required data resources include access to records from Irish Water, Local Authorities, National Waste Collection Permit Office, selected permitted FOG waste hauliers and FOG waste disposal sites in Ireland and the UK. Surveys will be carried out with the stakeholders to establish areas covered, volumes of FOG collected and location/method of FOG waste treatment in place. This data can be gathered by agreement with each stakeholder. The study will focus on the main Irish urban centres including Dublin and Galway.

The studied FOG disposal sites will be determined by using information gathered by the Dublin FOG office to establish the main FOG waste hauliers and disposal sites currently in use. This data can be accessed through the project partner Noonan who currently run the FOG programme in Dublin and South Dublin. Permission from Irish Water and the Local Authorities involved will be acquired. It is not currently clear what level of data is available within the other Local Authorities in Ireland regarding FOG management. However, volumes of FOG produced can be estimated, using data from Dublin, based on the type of the establishment (hotel, restaurant, takeaway, etc.). Based on information compiled by the Local Authority Services National Training Group (LASNTG)-Water Services Training Group (2012), a 2011 FOG average was established for FSO type in DCC (Table 2). This data is being reassessed as part of a parallel project currently being carried out by David Gibbons.

<table>
<thead>
<tr>
<th>Type of Establishment</th>
<th>Average FOG generated per FSO per year (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convenience Store/Deli</td>
<td>232</td>
</tr>
<tr>
<td>Fast food restaurant</td>
<td>906</td>
</tr>
<tr>
<td>Full service restaurants</td>
<td>828</td>
</tr>
<tr>
<td>Hospital</td>
<td>2352</td>
</tr>
<tr>
<td>Hotel</td>
<td>1596</td>
</tr>
<tr>
<td>Public House</td>
<td>624</td>
</tr>
</tbody>
</table>

Life Cycle Assessment and Data Mapping
A life cycle assessment approach will be established on selected permitted hauliers. There are approximately 20 permitted FOG haulier companies that are commonly used by FSOs in Dublin. The majority of these are authorised for FOG collection nationwide. The lifecycle assessment approach will be undertaken for the FOG management activities to analyse the relative environmental and revenue impacts of the processes used in FOG waste collection and treatment. Lifecycle assessment models are environmental assessment tools that consider environmental impacts of a product, process and system from cradle to grave. This will take into the account the current transportation methods in place and whether these can be improved upon. In Ireland, road transportation is the main method for distributing FOG waste to disposal sites. GIS will be utilised to map the current routes being used and determine the most cost and carbon efficient routes/locations for FOG disposal in relation to high FSO density urban areas. Strategically placed sites can be proposed to reduce the overall carbon footprint involved in FOG management.
Results and Discussions

This research is in the early stages of development. It is projected that FOG waste utilisation can be improved in Ireland by studying the current processes in place. Diverting FOG from the sewers is the first step in FOG waste management. There are no official figures for the FOG waste stream nationally. In Dublin, there are over 2000 FSOs. Currently in Dublin, pump outs of the grease traps are required every three months at a minimum. With the minimum size of passive grease traps at 100 litres, it is clear that there is a substantial supply of FOG waste available.

Conclusion

Alternative treatment routes should be considered that take advantage of the high energy potential of FOG waste. A study must first be carried out to evaluate the energy and revenue opportunities present in the management of FOG waste in Ireland. With a national management programme that raises awareness of the potential of FOG waste as a resource, an existing disposable waste stream can be transformed into a renewable energy source.

Acknowledgements

This project is funded by the Irish Research Council and Noonan Services Group in partnership with Evolution Environmental Services as part of the Employment Based Postgraduate Research Programme. The authors would like to thank all parties for their support. Further details regarding this project and a parallel project being carried out by David Gibbons are available at: http://ssu.ie/research/fog/

References


ASSESSING DUBLIN CITY COUNCIL’S FAT, OIL AND GREASE (FOG) PROGRAMME THROUGH GREASE TRAPPING SYSTEM (GTS) INSTALLATION AND MAINTENANCE

David Gibbons¹, Michael O’Dwyer² and Thomas P. Curran¹
¹UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland
²Evolution Environmental Services Ltd in partnership with Noonan Services Group, The Guinness Enterprise Centre, 8 Taylor’s Lane, Dublin 8

Abstract

Fat, oil and grease (FOG) is a waste by-product of food production and is a major contributing factor in 50-75% of in-line sewer blockages. FOG forms a hardened solid in pipes as a result of physical and chemical property changes that occur within the sewer network, reducing capacity, and increasing the risk of overflow. In 2008 Dublin City Council (DCC) introduced a FOG Programme to address recurring FOG related blockages within the sewer network. This paper is an update on work being carried out to assess the overall efficacy of this programme, and its impact in reducing the social, economic, and environmental impact of FOG waste on the urban environment in Dublin. Over 2,000 environmental monitoring inspections performed within a chosen study area were reviewed to monitor: grease trapping system (GTS) installation and maintenance. The study found that the installation of suitable GTS increased from 14% in 2008 to 80% in 2014. Similarly, compliance with the maintenance and best management practices conditions of the FOG Programme have improved steadily throughout the time period resulting in over 110x10³ litres of grease trap waste being redirected from the sewer network in the study area in 2014.

Introduction

Fat, oil and grease (FOG) discharges to the sewer network from domestic, commercial and industrial sources, pose a significant risk to the urban environment (Keener et al. 2008, Williams et al. 2012, Mattsson et al. 2014). FOG accumulates in sewer systems in the form of hardened solids (He et al. 2011, Williams et al. 2012), restricting sewer pipe capacity, resulting in line blockages and sewer overflow (US EPA 2004). Sewer overflows release high concentrations of pathogens, nutrients, and solids that impose a risk to public health and the environment (He et al. 2011). In 2013/14, water companies across England and Wales spent about £70 million clearing more than 300,000 sewer blockages, of which FOG was the cause of, or a contributing factor to, up to 75% of incidents (CC Water 2014, Water UK 2015). In 2004, the United States Environmental Protection Agency (US EPA) identified FOG as the most common cause (47%) of line blockages resulting in uncontrolled sewer overflow events (US EPA 2004). FOG also poses a significant problem at the wastewater treatment plant. A recent EU funded project estimated that the cost of the oil factor (or FOG) in the wastewater treatment process is up to 25% (RecOil 2015), as a result of the difficulty and energy consumption involved in the process of separation and bio-degradation. Similarly in 2011, the US EPA identified that “the greatest threat of obstruction in Publically Owned Treatment Works comes from polar fats, oils, and greases (FOG) of animal and vegetable origin” (US EPA 2011).

In 2008, following an increase in FOG related problems (over 1,000 FOG related sewer blockages per year), Dublin City Council (DCC) introduced a trade effluent discharge licencing programme in accordance with the Local Government (Water Pollution) Act 1977, to target FOG discharges from food service outlets (FSOs). The programme requires FSOs to install and maintain suitable grease trapping systems (GTSs) and implement best management practices (BMPs) on-site to control FOG at source. Environmental Inspectors audit FSOs between 2-6 times per annum to assess their compliance with the programme conditions and provide on-site training.

The objective of this paper is to give spatial and temporal representation, to the effect the DCC FOG Programme has had in reducing the risk posed by FOG to the urban environment.
Study Area

A small catchment area within the DCC operational area, containing approximately c. 160 food service outlets (FSOs) was assessed over a period from 2008-2014 (c. 7% of the FSOs in Dublin), was selected as the study area. The catchment has an area of approximately 0.25km² and almost 7km of pipelines. The catchment was selected as the number of FSOs operating within the catchment boundary has remained stable throughout the period from 2008-2014: 143 FSO businesses operated within the catchment at 139 different premises in 2008, while 164 FSO businesses operated at 159 different premises in 2014, an increase of 14% during a period of economic contraction in Ireland. The stability and growth in the number of FSOs, is in line with predicted urbanisation and dietary trends outlined by Popkin (1999) and Marvin & Medd (2006) and will allow for future comparisons with urban areas not currently operating FOG Programmes.

Methodology

A comprehensive field and desk study was undertaken in the study area to monitor grease trapping system (GTS) installation and maintenance in the period from 2008-2014. 485 field inspections were performed in FSOs throughout 2014. A study of the historic compliance of the FSOs was also performed through a desktop review of inspector notes and correspondence from over 1,500 historic environmental monitoring inspections performed throughout 2008 and 2012. Sites are evaluated in accordance with the standard operating procedure of the DCC FOG Programme, an abridged description of the inspection protocol, for the purpose of the results detailed in this paper is outlined below, and assigned a risk category in accordance with Table 1, below.

Grease Trapping System Assessment

The DCC FOG Programme requires that FSOs install grease trapping systems (GTSs) that meet specified sizing and operational standards, dependent on the type of GTS employed. Passive grease interceptor units, or gravity separation tanks, are required to meet the European Standard for such units (IS EN 1825-1&2). Hydro-mechanical grease recovery units (GRUs) are required to be fitted in accordance with the US PDI-G10 standard, as there is currently no Irish or European Standard for these units. Each type of unit has specific maintenance schedules and requirements. The suitability, along with the condition, and maintenance regime, of the installed equipment was collated during the study period.

Best Management Practices Assessment

FSOs are required to implement best management practices (BMPs) on-site to reduce the quantity of FOG waste and solids entering the drainage network as part of the DCC FOG Programme. The BMPs assessed during the study included: the washing up procedure on-site (i.e. the implementation of dry-wiping and rinsing etc.), the location of washing up activities on-site and the installation of appropriate signage (i.e. to ensure washing was not taking place in equipment not connected to GTSs), and the storage and collection of all FOG waste streams: including used cooking oil (UCO) and grease trap waste (GTW). The quantity of FOG waste recovered by permitted waste hauliers was also assessed during the environmental inspection process.

Risk Rating

FSOs were assigned a Risk Rating in accordance with Table 1, below, based upon their performance during the on-site inspection and the review of the collated data from the historical inspection notes. Table 1 is a slightly amended risk table from the risk table implemented in the DCC FOG Programme to determine the frequency of site inspections and the annual licencing charge payable by the FSO – the higher risk a FSO poses the drainage network, the higher the annual licencing charge, in accordance with the Waste Framework Directives “polluter pays principle”.

Risk Mapping

The results of the site and desktop studies were mapped using ArcGIS software to generate maps of the applied FOG risk to the drainage network within the catchment area.
Table 1: Risk rating table for food service outlets (FSOs)

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1 – Unacceptable</td>
<td>• Premises has <strong>no GTS installed</strong></td>
</tr>
<tr>
<td>Category 2 – High Risk</td>
<td>• Premises has <strong>undersized/unsuitable GTS installed</strong></td>
</tr>
<tr>
<td></td>
<td>• <strong>GTS is in poor condition</strong> and does not meet the required maintenance</td>
</tr>
<tr>
<td></td>
<td>standards</td>
</tr>
<tr>
<td>Category 3 – Medium Risk</td>
<td>• <strong>GTS is overdue minimum maintenance requirements</strong> - but not in serious</td>
</tr>
<tr>
<td></td>
<td>breach of requirements</td>
</tr>
<tr>
<td></td>
<td>• FOG disposal records are not available for inspection, incomplete, or</td>
</tr>
<tr>
<td></td>
<td>inaccurate.</td>
</tr>
<tr>
<td>Category 4 – Low Risk</td>
<td>• <strong>GTS is in good condition</strong> and all required information is available and</td>
</tr>
<tr>
<td></td>
<td>up to date</td>
</tr>
</tbody>
</table>

Results and Discussion

143 FSOs were operating within the study area at the beginning of 2008. Of these, just 21 FSOs (14.3%) had suitable GTSs installed and none of these GTSs were classified as “Category 4 – Low Risk”. By year end, 2008, GTSs installations had increased to 50.3% of FSOs. In November 2014, there were GTSs installed in 127 of the 159 FSOs operating in the study area (79.8%) and compliance with the maintenance requirements and BMPs varies between 55% (Category 4) and 99% (Category 3 & 4) as a result of minor non-compliances. Figures 1 & 2, below, provide a synopsis of the GTSs installations and FSO compliance in the study area. The net result of these efforts was the recording of the redirection of 110x10^3 litres of grease trap waste (GTW) from the sewer network in the study area in 2014, a 275% increase from an estimated total of 40x10^3 litres of GTW in 2008, based upon the date of GTS installation and the rate of GTW produced per facility type.

![Figure 1: Number of suitable GTS installed in the study area during the study period](image)

![Figure 2: Comparison of grease trap system (GTS) installations and maintenance, per facility type, in the Study Area at the beginning of 2008 (left) and November 2014 (right)](image)
Conclusion

The DCC FOG Programme has been effective in reducing the risk of an in line sewer blockage occurring in the sewer network through achieving a significant reduction in the quantity of FOG entering the drainage network as a result of the FOG source control programme. The development of the FSO FOG risk maps using ArcGIS has given a spatial representation to the GTS installations and increasing levels of compliance from FSOs with the requirements of the programme. The results represented in the study area correlate with the reduction in FOG blockages in the entire DCC functional area from over 1,000 per annum to less than 100 in 2014.

Acknowledgements

This project is funded by the Irish Research Council and Noonan Services Group as part of the Employment Based Postgraduate Research Programme. The authors would like to thank both parties for their support. The authors would also like to thank Dublin City Council and Irish Water for their support of the project. Further information is available at: http://ssu.ie/research/fog/.

References


IDENTIFICATION OF ANTIMICROBIAL RESISTANT ORGANISMS IN SURFACE WATER ECOSYSTEMS AND RISK ASSESSMENT STRATEGIES FOR THEIR CONTROL

Eithne O’Flaherty and Enda Cummins
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Antimicrobial Resistant Organisms (AROs) are of public health concern particularly in water ecosystems. If surface water ecosystems are polluted with AROs this will have huge repercussions on human health. It is necessary to prevent and reduce the risk caused by AROs on human health as soon as possible in order to prevent an ARO epidemic. Risk assessment can be a useful tool in evaluating the risk to human health from AROs. Identifying the areas and reasons why AROs are spreading and expanding can lead to taking the necessary steps to reduce the hazards and the risks to human health. This literature review will analyse current and past research in this area and will look at the main risk factors influencing the AROs in surface water ecosystems.

Introduction

Antibiotic resistance is becoming an increasing threat to public health through surface water ecosystems. Water is a necessity for human survival and if the surface water ecosystems are polluted with antimicrobial resistance organisms, human health is at risk of illness or even death. An estimated 700,000 deaths are caused by antimicrobial resistant organisms worldwide annually and it is estimated that 10 million people could be dying annually by 2050 if the problem is neglected (WHO 2014a). Antimicrobial resistance is a complicated issue as it involves many different contributing factors, eliminating one factor will not significantly reduce its presence. A combination of preventive steps is required to help eliminate antimicrobial resistance (WHO 2001).

There are several areas in the environment that AROs are present in and they include hospital wastewater, wastewater treatment plants (WWTP) effluent water, irrigated land, animals, crops, recreational water and the ocean. Hospital wastewater harbours antibiotics and AROs even after the hospital effluent has been treated by a WWTP (Picao et al., 2013, Rodriguez-Mozaz et al., 2015, Verlicchi et al., 2012). According to Verlicchi et al., 2012 in order to help reduce the risks from hospital effluent, treatment of hospital wastewater should be separate to urban wastewater treatment as levels of antibiotics are considerable higher in hospital effluent. WWTP should have regulations on the acceptable levels of antibiotics and AROs that are being discharged from the plants as the effluent can make their way into several environments and can result in a public health risk (Picao et al., 2013). Wastewater and effluent from WWTP are used in irrigation, when the land is irrigated the crops and animals that use the land may adsorb and consume the antibiotic residues. Antibiotics are also used to help stimulate growth in farm animals and the unmetabolized antibiotics can be excreted onto the land. Humans can be at risk of coming into contact with AROs through the use of recreational water while swimming or other recreational activities. The ocean also harbours AROs and antibiotics as raw wastewater is sometimes directly discharged into the ocean from cargo and cruise ships. Aquatic environments provide the ideal vehicle to aid in the spread of antimicrobial resistant organisms throughout the planet (Rodriguez-Mozaz et al., 2015). Currently there is a lot of research evidence of AROs presence in the environment but the magnitude of the risk to human health is relatively unknown.

The objective of this study is to evaluate existing literature sources and identify ARO of concern and to identify suitable modelling tools for evaluating their risk to environmental and human health.
Materials and Methods

The literature review will use current, past, national, international scientific research papers and web sources to compile the data required for this study. The data gathered will identify AROs found in water ecosystems that pose the greatest risk to the public health. The identification of risk assessment modelling tools and the appropriate approach for evaluating AROs risk to human health is described in the following section.

Identification of risk assessment models and software

Risk assessment is a valuable tool to help evaluate a hazard and the risks exhibited by that hazard (Duffy et al., 2006). There are two main approaches to risk assessment they include qualitative and quantitative risk assessment. Qualitative uses board categories and quantitative uses numerical values to evaluate a hazard and the risks associated with that hazard. When performing a risk assessment there are four main steps to take, they include; hazard identification, exposure assessment, hazard characterisation and risk characterisation. Hazard identification involves identifying the possible risks that may cause harm to humans/environment. Exposure assessment identifies the pathway and level of exposure to human/environment. Hazard characterisation relates the amount of a hazard consumed to a clinical outcome (illness). Risk characterisation brings together the information found from the exposure assessment and the hazard characterisation to establish an estimate of the risk and to the human/environment concerned (Salisberg et al., 2002; Duffy et al., 2006).

There are many different risk assessment models and software available but to choose the appropriate one depends on the hazards and risks that are under investigation. Table 1 presents a number of risk assessment models explaining the advantages and disadvantages of each model and an example of the use of the model in research. There are also a number of software packages that can be used for example; @RISK Palisade, PRISM, CRYSTAL BALL, CALTOX, RISKPRÓ and LEADSREAD.

<table>
<thead>
<tr>
<th>Model name</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Example and reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>PhATE (Pharmaceutical Assessment Transport Evaluation model)</td>
<td>Highly accurate</td>
<td>Requires detailed data</td>
<td>Used to predict environmental concentrations of paroxetine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Cunningham et al., 2004)</td>
</tr>
<tr>
<td>GREAT-ER (Geo-referenced Regional Exposure Assessment Tool for European</td>
<td>Highly accurate</td>
<td>Requires a significant amount</td>
<td>Used to evaluate phototransformation of propranolol hydrochloride</td>
</tr>
<tr>
<td>Rivers)</td>
<td></td>
<td>of data</td>
<td>in UK and US rivers (Robinson et al., 2007)</td>
</tr>
<tr>
<td>GWAVA (Global Water Availability Assessment)</td>
<td>Useful for exploring</td>
<td>Lacks accuracy</td>
<td>Evaluated the concentrations of 17α-ethinylestradiol, 17β-</td>
</tr>
<tr>
<td></td>
<td>large geographical</td>
<td></td>
<td>estradiol and diclofenac in European rivers (Johnson et al.,</td>
</tr>
<tr>
<td></td>
<td>areas</td>
<td></td>
<td>2013)</td>
</tr>
<tr>
<td>EUSES (European Union System for Evaluation of Substances)</td>
<td>Highly accurate and</td>
<td>Requires a significant amount</td>
<td>Analysed 17α-ethinylestradiol, carbamazepine, sulfamethoxazole,</td>
</tr>
<tr>
<td></td>
<td>recommedede by</td>
<td>of data</td>
<td>iopromide and tonalide from concentration levels found in</td>
</tr>
<tr>
<td></td>
<td>European</td>
<td></td>
<td>literature (Liebig et al., 2006)</td>
</tr>
<tr>
<td></td>
<td>Commission</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results and Discussion

As the literature review is ongoing the expected results are discussed. The data collected to date identifies a number of antimicrobial resistant organisms of concern to human health; they include
Escherichia coli, Klebsiella pneumonia, Staphylococcus aureus, Streptococcus pneumonia, Nontyphoidal Salmonella, Shigella species and Neisseria gonorrhoea (Table 2). These AROs are concerning to public health because of the resistance they exhibit to antibiotics and the difficulty in treating the resistant organisms. If these AROs are present in water ecosystems and come in contact with the public the consequences could be life threatening. There is evidence that there is an increase in antibiotic resistant organisms in Europe, Figure 1 shows concerning evidence that from 2010 to 2013 AROs were increasing.

The risk assessment methods that have been identified to date include PhATE, GREAT-ER, GWAVA and EUSES, further investigation is required to find more risk assessment models and software. Comparison of models and software is necessary to identify the suitable tools for performing a risk assessment on the risk of AROs to the public health from water ecosystems. A unique combination of risk assessment models and software may be necessary to create the appropriate risk assessment.

Table 2. Main AROs, antibiotics and risks to human health of main concern (WHO 2014b).

<table>
<thead>
<tr>
<th>Antimicrobial Organism</th>
<th>Resistant Resistance to</th>
<th>Risk to human health</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Escherichia coli</em></td>
<td>Cephalosporins</td>
<td>Urinary tract infection, blood stream infection</td>
</tr>
<tr>
<td></td>
<td>Fluoroquinolones</td>
<td></td>
</tr>
<tr>
<td><em>Klebsiella pneumoniae</em></td>
<td>Cephalosporins</td>
<td>Pneumonia, blood stream infection, urinary tract infection</td>
</tr>
<tr>
<td></td>
<td>Carbapenems</td>
<td></td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>Methicillin</td>
<td>Wound infection, blood stream infection</td>
</tr>
<tr>
<td><em>Streptococcus pneumoniae</em></td>
<td>Penicillin</td>
<td>Pneumonia, meningitis, otitis</td>
</tr>
<tr>
<td><em>Nontyphoidal Salmonella</em></td>
<td>Fluoroquinolones</td>
<td>Food borne diarrhoea, blood stream infection</td>
</tr>
<tr>
<td><em>Shigella species</em></td>
<td>Fluoroquinolones</td>
<td>Diarrhoea</td>
</tr>
<tr>
<td><em>Neisseria gonorrhoea</em></td>
<td>Cephalosporins</td>
<td>Gonorrhoea</td>
</tr>
</tbody>
</table>

Figure 1. Escherichia coli resistance to fluoroquinolones, third-generation cephalosporins and aminoglycoside in EU countries (ECDC 2014)

*Population weighted mean of 30 EU countries that provided antimicrobial resistance data

Conclusion

The data collected from this study will identify the AROs that are causing the greatest threat to human health from the water environment and it will compare and discuss risk assessment models and software. The information gathered will aid in educating the public on the dangers of AROs and will
highlight the benefits of a risk assessment as a method of identifying the level of risk to human health from AROs.

Acknowledgements

The authors would like to thank the Environmental Protection Agency and the Water JPI programme for their financial support

References


A QUANTITATIVE RISK RANKING OF CLASSIC AND “EMERGING CONTAMINANTS” IN BIOSOLIDS AND RISK TO HUMAN HEALTH

Rachel M. Clarke, Enda Cummins

UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland

Abstract

This study aims to quantitatively assess the risk from organic contaminants to surface water quality and consequently to human health following exposure through drinking water. A Monte Carlo simulation model which includes the predicted environmental concentration in runoff (PEC\textsubscript{runoff}) combined with an exposure estimate and the no observed adverse effects level (NOAEL) as a toxicity endpoint, resulting in a chemical intake toxicity ratio (RR) for each contaminant. A selection of organic contaminants were evaluated based on site specific inputs and probability density distributions were used to take account of uncertainty and variability in model inputs. Geological and meteorological data were based on site specific data while compound specific data (e.g. concentration in biosolids, soil sorption coefficient (Koc), soil organic carbon (Soc)) and behavioural indicators (e.g. NOAEL) were sourced from a selection of peer reviewed literature and online chemical databases. Results for PEC\textsubscript{runoff} and health based risk (RR) show that the contaminant nonylphenol (NP) ranked the highest (mean values 1.1 e-02 µg/l and 5.4 e-07, respectively). Sensitivity analysis revealed that the soil sorption coefficient (Koc) and soil organic carbon (SOC) were the most important parameters that affected model variance.

Introduction

Approximately 10 million tonnes of sewage sludge are produced in the EU member states each year, with 3.7 million tonnes dry solids (DS) being recycled to land (Kelessidis and Stasinakis, 2012). Land application of digested municipal sludge, also known as biosolids, is a possible alternative for reusing biosolids and an alternative to land fill, which has risen significantly in the last decade. The sewage sludge directive (86/278/EEC) was established to encourage the use of sewage sludge (biosolids) in agriculture and to regulate its use to prevent harmful effects on soil, vegetation, animals and man, whilst ensuring the nutrient requirements for plants are met (etc. nitrogen, phosphorus and potassium) and not impinging on soil, surface or groundwater quality. Apart from essential nutrients, biosolids may also contain potentially toxic compounds (e.g. persistent organic contaminants (POPs)) and emerging contaminants (e.g. pharmaceuticals and personal care products (PPCPs)). Recent studies have shown that overland transport from biosolid amended lands can impact the quality of surface or ground water through runoff of organic contaminants (Topp et al., 2008), especially after extreme weather events, including heavy rainfall or flooding. The detection of POPs and PPCPs has been widely reported in biosolids, surface water and drinking water (Díaz-Cruz et al., 2009, de Jongh et al., 2012, Daughton, 2010). A suite of contaminants including; POPs (polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxin furrans (PCDD/Fs) and polybrominated diphenyl ethers (PBDEs)), PPCPs (carbamazepine (CBZ), triclosan (TCS), triclocarban (TCC), propranolol and metoprolol), (perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA)) substances, natural hormones (estrone and 17βestradiol), surfactants (nonylphenol (NP), its short ethoxy chain precursors nonylphenol mono-(NP1EO), and di-ethoxylate (NP2EO)) and bisphenol A (BPA) were selected based on the risk factors; persistence, bioaccumulation and toxicity (PBT).

The primary objective of this study is to develop a quantitative risk ranking assessment model for “classic” and emerging contaminants in biosolids in Irish agriculture. All contaminants will be ranked to identify those that may pose the greatest risk to surface and ultimately human health through water consumption.
Materials and methods

A probabilistic model was constructed in Microsoft Excel (incorporating @Risk 6.0) to estimate human exposure to selected organic contaminants through drinking water and which emanate from biosolids used for land application. Probability density distributions were used to take account of uncertainty and variability in inputs. A database of inputs was formulated (including e.g. contaminant levels in biosolids ($C_{\text{sludge}}$), soil sorption coefficient ($K_{\text{oc}}$), soil organic carbon (Soc) and site specific inputs (e.g slope, rainfall, application rate, bulk density, soil type)) by collating data from International/European peer reviewed journals, online chemical databases (Chemfinder, CAS and, ECHA, ESIS), regulatory agency data and internet search engines. A flow diagram of the model processes and accompanying equations are given in Figure 1.

![Flow diagram of the quantitative risk ranking model for organic contaminants.](image)

The model for PEC in soil and runoff was modified from Trevisan et al. (2009) and adapted for Irish specific conditions. A Monte Carlo simulation technique was applied to sample from the input distributions to create an output distribution. The water consumption in Ireland was modelled using a lognormal distribution with a mean value of 0.564 L and a standard deviation of 0.617 according to a survey on adult nutrition conducted by the Irish Universities Nutrition Alliance (IUNA) which was based on 1274 consumers (IUNA 2011). The mean body weight of adults was also obtained from the same report. The average body weight of Irish males and females was estimated to be 86.2 and 70.0 kg respectively and was modelled using a uniform distribution to model the variation in bodyweight. To evaluate the human health risk exposure, the NOAEL (mg/kg) was used as a toxicity endpoint in the model and is contaminant specific.
Results and discussion

The environmental fate of selected organic contaminants was traced from biosolid application to drinking water consumption. Outputs from the model include the PEC_{soil} of each contaminant, subsequent PEC_{runoff} to surface waters and the chemical toxicity ratio (RR). Table 1 shows the top 5 simulated ranking results according to hazard and exposure based risks. The results of the PEC_{runoff} indicate that from the selected contaminants analysed, the highest PEC_{runoff} value obtained was from NP with a mean PEC_{runoff} value of 1.1 e-02 µg/l (95th percentile 4.8 e-02 µg/l). This was mainly attributed to the initial concentrations of NP in biosolid amended soil (5.69 mg/kg).

Table 1: Comparison of the ranking hazard based risk versus human health based risk.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Ranking according to hazard based risk (PEC_{runoff}) µg/l mean (5th, 95th)</th>
<th>Rank</th>
<th>Contaminant</th>
<th>Ranking according to health based risk (RR) mean (5th, 95th)</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP</td>
<td>1.1 e-02, (1.8 e-04, 4.8 e-02)</td>
<td>1</td>
<td>NP</td>
<td>5.4 e-07, (9.8 e-10, 1.5 e-06)</td>
<td>1</td>
</tr>
<tr>
<td>NP1EO</td>
<td>4.1 e-03, (2.9 e-04, 5.9 e-03)</td>
<td>2</td>
<td>NP1EO</td>
<td>5.2 e-07, (6.8 e-09, 2.4 e-06)</td>
<td>2</td>
</tr>
<tr>
<td>TCC</td>
<td>8 e-04, (6.2 e-05, 2.1 e-03)</td>
<td>3</td>
<td>Estrone</td>
<td>4.7 e-08, (2.2 e-10, 1.6 e-07)</td>
<td>3</td>
</tr>
<tr>
<td>TCS</td>
<td>1.8 e-04, (4.9 e-06, 6.2 e-04)</td>
<td>4</td>
<td>PCBs</td>
<td>2.2 e-08, (2.2 e-11, 6.3 e-08)</td>
<td>4</td>
</tr>
<tr>
<td>BPA</td>
<td>6.6 e-05, (1.0 e-06, 1.3 e-04)</td>
<td>5</td>
<td>BPA</td>
<td>1.4 e-08, (1.2 e-10, 2.6 e-08)</td>
<td>5</td>
</tr>
</tbody>
</table>

These results indicate that that the spreading of biosolids on agricultural land can result in considerable concentrations in the environment. Ekelund et al., (1990) demonstrated that low exposure to NP (<0.1 µg/l) can cause severe reproductive disorders and even death to freshwater organisms (e.g. crustaceans, fish, insects, nematodes, zooplankton etc.).

Figure 2: Sensitivity analysis of input parameters on the health based risk of NP

Spearman Rank Order Coefficient Value
Based on human exposure risk ranking, the top ranking contaminant is NP with a mean chemical toxicity intake ratio (RR) value of 5.4 e-07, (95th percentile 1.5 e-06) (Table 1). The results highlight the potential oversight of potentially harmful contaminants of human health concern if just PEC
 runoff of contaminants is used in risk ranking. A Sensitivity analysis based on rank order correlation was carried out to assess how the model predictions are dependent on variability and uncertainty in the model input parameters. Results revealed that the soil sorption coefficient (Koc) and soil organic carbon (SOC) were the most important parameters (correlation coefficient values -0.51 and 0.23, respectively) and affected the variance in model predictions (Figure 2). This highlights the importance of soil and contaminant properties in influencing risk estimates.

Conclusion

A probabilistic model was developed to rank “classic “and emerging contaminants according to PECrunoff and resulting chemical intake toxicity ratio (RR). The PECrunoff was combined with the likely human exposure and the NOAEL in order to create a human health risk based model. The highest rank obtained for PECrunoff was NP and for human health risk (NOAEL) was also NP. A sensitivity analysis revealed that the soil sorption coefficient (Koc) and the soil organic carbon (SOC) were the most important parameters that affected model variance. This study highlights the relevance of effective wastewater treatment, as the initial concentrations of the contaminant in the biosolids influence the concentration in runoff and ultimately drinking water. Thus, as more water is consumed, the risk of exposure is increased. The model developed in this study is of importance for risk managers in providing a ranking of potential chemical hazards resulting from the spreading of biosolids on agricultural land, while highlighting some emerging contaminants requiring vigilance in the future.

Acknowledgements

The authors acknowledge the Irish EPA for the funding of this project under the STRIVE Programme (2007-2013). Project partners include Teagasc Johnstown Castle and NUI Galway.

References

Ekelund, R., Bergman, Å., Granmo, Å. and Berggren, M. (1990) 'Bioaccumulation of 4-nonylphenol in marine animals— A re-evaluation', Environmental Pollution, 64(0), 107-120.
THE ENVIRONMENTAL IMPACT OF PASTEURIZATION AND UHT IN DAIRY PROCESSING

Rui Liu and Nicholas M. Holden

UCD School of Biosystems Engineering. University College Dublin, Belfield, Dublin 4, Ireland

Abstract

As the pillar commodity of the agricultural and national economy of Ireland, the dairy industry has developed rapidly during the last 10 years. Following a growing demand for dairy products around the world, the environmental impact per unit product is important. Thermal treatment is one of the most important unit operations in the production of liquid milk. This research used LCA as a tool to compare the sterilization effect, nutrition values and environmental footprint of Pasteurization (Low Temperature Long Time, High Temperature Short Time) and Ultra High Temperature treatments of producing liquid milk. The approach can be used to identify the best choice of thermal treatment for different purposes in the dairy industry.

Introduction

As a result of the growing population and changing diet structure around the world, especially in developing countries, the demand for dairy production is expected to rise (Food Harvest 2020). According to Kryserlingk et al. (2012) this change will cause significant environmental problems, such as water pollution and greater GHG (greenhouse gases) emissions. These problems are slowing down the transition to sustainable dairy production. Based on the demand for energy during dairy processing, the dairy industry has a great potential to show genuine leadership in promoting sustainable initiatives, particularly in reducing energy usage (Tiwari, Norton and Holden, 2014). Although products differ in their manufacturing technologies, the main unit operation usually include thermal processing, refrigeration and mechanical shearing operations (mixing and homogenization), which involve significant energy usage and generate environmental footprints (Tiwari, Norton and Holden, 2014). From an environmental viewpoint, the most important unit operation for the production of fluid milk is thermal treatment. It involves raising milk to a specific temperature and holding it at that temperature for sufficient time to destroy any pathogenic bacteria that are present in the milk and to render it safe for human consumption (Tiwari, Norton and Holden, 2014). There are three different approaches: pasteurization, UHT (ultra-high-temperature) and secondary sterilization. They can all be used to proces liquid milk or other dairy products. However the sterilizing effect, nutrition values and the environmental footprint are different. Life Cycle Assessment (LCA) (based on the ISO 14040) is a suitable tool to analysis the impact of each kind of thermal treatment.

The objective of this work was to using LCA to quantify the environmental impact of Pasteurization and Ultra High Temperature treatment in the dairy industry.
Materials and Methods

A sequential approach was defined:
1. Review of the thermal treatments used by the dairy industry, especially for liquid milk.
2. Definition a LCA model to compare the environmental footprint of Pasteurization and UHT.
3. Integrate the results with other data to suggest how to choose the best temperature and the time of thermal treatment for different purposes and environmental requirements.

The goal of this study will be evaluating the environmental footprint of pasteurization and UHT while producing liquid milk. The scope of this study will be based on the boundary of the dairy processing plant. The functional unit will be 1 kg of packaged liquid milk. The software GaBi will be used to build the processing model.

Results and Discussion

The technical difference between LTHT (low temperature long time), HTST (high temperature short time) and UHT (ultrahigh temperature) are shown in Table 1. The nutritional influence of Pasteurization and UHT are shown on Table 2. According to the report of Euromonitor (2002), the market share of pasteurization milk in Canada, America, Japan and most Europe countries is greater than 99%; UK, Netherlands, Australian and New Zealand is also greater than 95%. However, in over 200 countries around the world, like China, the share of the liquid milk market satisfied by UHT is over 10%. This is mainly because of the storage temperature and storage time of pasteurization milk is strict. The cold chain of storage for liquid milk, especially for pasteurized milk, also needs to be considered for the environmental footprint. However, after high temperature, especially UHT sterilization, part of the soluble calcium in milk will become insolubly, like tricalcium phosphate. These insoluble calcium are hard to digest and absorb by humans. At the same time, milk stone (whose main components are protein, fat, insoluble calcium, phosphorus, magnesium and other minerals) will form and adhere to the sterilizer. The milk stone is associated with problems with the cleaning process (Zhang, Fujii and Aoki, 1996). The energy consumption will increase if a poor choice of cleaning process is made. Comprehensive consideration of nutrition losses, environmental cost and consumer requirement should be considered to make the best choice of thermal treatment.

Conclusion

The purpose of this study is to compare the LCA method to evaluate the environmental footprint of LTHT, HTST and UHT. In order to make a perfect choice of thermal treatments the nutrition and safety requirement also need to be satisfied at the same time.

Acknowledgement

The author is working under the foundation of CSC-UCD Scholarship Scheme.
<table>
<thead>
<tr>
<th></th>
<th>LTHT</th>
<th>HTST</th>
<th>UHT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature</strong></td>
<td>63</td>
<td>72</td>
<td>135~150</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>30min</td>
<td>15s</td>
<td>1~8s</td>
</tr>
<tr>
<td><strong>Effect</strong></td>
<td>Make the enzyme inactivation, and destruction of heat-sensitive microbiology and pathogenic bacteria</td>
<td>To kill all the pathogenic microorganisms</td>
<td>Kill all microorganisms (including bacteria and spores)</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>5<del>7 for 8</del>10days</td>
<td></td>
<td>Room temperature</td>
</tr>
<tr>
<td><strong>Advantage</strong></td>
<td>Simple, convenient, sterilization effect was 99%, and the pathogenic bacteria completely killed</td>
<td>1. Less covering area</td>
<td>1. Remarkable sterilization effect (all microorganisms are killed, including bacteria and bacillus)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Large capacity, continuous producing is possible,</td>
<td>2. Less chemical or nutrition changes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Need less heating sources, the cost is low</td>
<td>3. Packaged products can be storage at room temperature for a long time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Operated in an airtight condition, which reduced the living contaminants</td>
<td>4. Suitable for continuous automatic producing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Less nutrition and flavor changes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Can be cleaned by CIP system, save labor, improve efficiency</td>
<td></td>
</tr>
<tr>
<td><strong>Disadvantage</strong></td>
<td>1. cannot kill the hemophilic, heat resistant bacteria, spores, and some remnants enzymes;</td>
<td>1. the number of remaining bacteria will be higher than LTHT</td>
<td>1. the consumption of steam and cooling is higher than HTST</td>
</tr>
<tr>
<td></td>
<td>2. equipment is relatively large and sterilization time is long</td>
<td>2. need strict temperature control test system</td>
<td>2. need strict temperature control system</td>
</tr>
</tbody>
</table>

Table 2: Nutrient losses (%) during thermal treatment

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>UHT</th>
<th>Pasteurization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cysteine*</td>
<td>34.0</td>
<td>4.6</td>
</tr>
<tr>
<td>Methionine*</td>
<td>34.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Lysine*</td>
<td>3.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Whey protein*</td>
<td>71.1</td>
<td>15.4</td>
</tr>
<tr>
<td>β-carotene**</td>
<td>6.1</td>
<td>-</td>
</tr>
<tr>
<td>VD**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>VE**</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>VC**</td>
<td>10-30.1</td>
<td>16.6</td>
</tr>
<tr>
<td>VB1**</td>
<td>9.4-18.0</td>
<td>11.9</td>
</tr>
<tr>
<td>VB2**</td>
<td>0-2.7</td>
<td>1.0</td>
</tr>
<tr>
<td>VB6**</td>
<td>3.2-7.3</td>
<td>0-8</td>
</tr>
<tr>
<td>VB12**</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>Folate*</td>
<td>35.2</td>
<td>7.3</td>
</tr>
</tbody>
</table>


**Ryley and Kajda, 1994

References


ECONOMIC TOOLS FOR SUSTAINABILITY ASSESSMENT

Wenhao Chen and Nicholas M. Holden

UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

This project compares two widely used economic assessment tools (cost benefit analysis and environmental life cycle costing analysis) for sustainability analysis. By comparing their merits and limitations, a matrix based life cycle costing method, considering the net present value of products and emissions in the whole production system will be developed.

Introduction

Sustainability can only be achieved within the context of the three pillars of sustainability: environmental, economic and social. Currently, there are many different economic methods suitable for environmental related economic assessment. Input-output (I-O) analysis, as a national level economic tool describes the deliveries and flows between sectors in terms of money within the system (Suh et al. 2004). And I-O based LCA can provide guidance for environmental impact mitigation strategy between different sectors at national scale. In order to evaluate the function of environmental policy, partial equilibrium models are common applied. These describe the outcome of a market or a set of markets by depicting the effect of environmental policy on consumption and production behavior. The results of partial equilibrium analysis depend on the assumption that all actors in markets maximize their pay-off by equating marginal benefits and marginal costs, and the assumption that all markets are cleared (Bouman et al. 2000). Compared to these national or sector level economic tools, cost benefit analysis and environmental life cycle costing analysis can be used for small scale evaluation at the farm system level. Cost benefit analysis (CBA) is a systematic tool developed in the early 20th century to evaluate the feasibility of a project (change in policy or management) by comparing the financial and environmental cost and benefit. The standard approach to valuing costs and benefits that occur at different times is based on the assumption that a Euro today is worth more than a Euro tomorrow. So a concept of ‘net present value’ (NPV) is introduced to reduce a time stream of costs or benefits to an equivalent amount in the price year’s monetary value. NPV can be obtained by equation (1).

\[ \text{NPV} = \sum_{t=0}^{N} \frac{CF_t}{(1+q)^t} \]  

Where: \( q \) = discount rate; \( t \) = evaluation period in years; \( CF \) = cash flows across \( N \) years including costs and benefits. If the NPV is positive, it means the project or the alternatives in the system are worthy of investment. Life cycle costing (LCC) analysis is a process of economic analysis, to assess the total cost of a product, including four main parts: cost of installation, operation, maintenance and /or decommission (Woodward 1997). Conventional LCC was developed in the 1960s, but with a focus on financial perspectives only. Costs borne by consumers or companies are considered, but environmental cost is not included. In addition, a conventional LCC does not always consider full life cycle, but only economic lifetime. In conventional LCC, net present value is also applied for discounting. Environmental LCC is an extension of conventional LCC, it covers the full life cycle of products and considers costs borne by other actors, e.g. waste disposal costs, expected CO\(_2\) taxes and global warming adaptation costs. Environmental LCC uses a steady state cost model in which all variables (including technology) are kept constant over time and discounting is not applied (Kloepffer 2008).

The objective of this project is to compare the advantages and disadvantages of cost benefit analysis and environmental life cycle costing analysis for sustainability assessment, and to evaluate matrix based life cycle costing analysis.
Materials and Methods

Theoretical comparison of CBA and environmental LCC

The greatest difference between environmental LCC and CBA is the boundary of the system. Environmental LCC covers the full life cycle of a product, while CBA focuses on the lifetime of a project, which is usually a part of a full life cycle. According to life cycle assessment methods, full life cycle consideration is very important for sustainability evaluation. For example, the environmental hotspot can be identified in production phase, like solar PV panel industry, or use phase, like paper print machine. Results of CBA, without considering the full life cycle of a product, may not provide producers or consumers a real economic profile of product system. In addition, environmental LCC can be used for comparison between different systems, however, the main purpose of CBA is for autonomous project evaluation, and there is no comparative meaning in NPV, which restricts the use of CBA for sustainability assessment. The relationship of conventional LCC and environmental LCC is illustrated in Figure 1. The boundary of environmental LCC covers a full life cycle, including emission cost of resource extraction and waste disposal cost in order to comply with LCA guidelines: from cradle to grave. In contrast with conventional LCC and CBA, there is no net present value applied in many environmental LCC studies. Even though, some researches may consider discounting the cost and benefit of products in system, they do not differentiate the timespan of discounting for each product in the system (Utne 2009, Mohamad et al. 2014). In addition, the monetary measures of different emissions could be complex and issues like diversification of measurement standard is unlikely to be avoided.

Figure 1: The conceptual framework of LCC (Rebitzer and Hunkeler 2003)

Theoretical assessment of Matrix based LCC

In order to define a suitable system boundary and allocate accurate discounting time for each product and emission associated with particular economic activities in a system, a matrix based LCC method is proposed. In this paper, we take a conceptual dairy farm as an example. The main units of the dairy farm include pre-farm nutrient and feed production, feed production on farm, the animal (including dry period and lactation period), waste management and other small units which should be considered in detail for LCC analysis. In each unit, we consider the main inputs and outputs that have monetary value for farmers. The system of monetization of emissions is not well established so emission flow is not included in this study. According to (Heijungs and Suh 2002), the basic computational structure of life cycle assessment can be expressed as (2)

\[
AS = f
\]  

(2)

Where A is the technology matrix containing all the flows in the system. Normally, A is known and can be quantified from LCI results. f is the final demand and considering the direction of input and output, f is the demand vector. S is the scaling vector. For our dairy
farm system, we can develop the technology matrix $A$, which contains the consumption of electricity, fuel, feed, fertilizer and animal replacement, land occupation, purchase of farm machines in each unit of dairy farm system. The emission flow can be added into the matrix $A$, if the cost of emission is defined and the farmers need to pay for the emission generated on the farm. In order to calculate the LCC based on the functional unit (in this study 1 kg of fresh milk), we define final demand $f_f$ as:

$$f_f = \begin{bmatrix} f_{11} & f_{12} & f_{13} & f_{14} & \cdots \\ f_{21} & f_{22} & f_{23} & f_{24} & \cdots \\ f_{31} & f_{32} & f_{33} & f_{34} & \cdots \\ f_{41} & f_{42} & f_{43} & f_{44} & \cdots \\ f_{51} & f_{52} & f_{53} & f_{54} & \cdots \\ f_{61} & f_{62} & f_{63} & f_{64} & \cdots \\ f_{71} & f_{72} & f_{73} & f_{74} & \cdots \\ f_{81} & f_{82} & f_{83} & f_{84} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \\ f_{mm} & \cdots & \cdots & \cdots & f_{mm} \end{bmatrix}$$

From (2), we can get $S$ by equation (3). However, if we want to calculate the invertible matrix $A^{-1}$, matrix $A$ must be square matrix. But matrix $A$ is defined by system, for instances, matrix $A$ may not be square matrix. So for matrix based LCC, functional unit based calculation may be not suitable. Considering this situation, the LCC result should be calculated based on the flows recorded in technology matrix $A$.

$$S = A^{-1} f_f$$

In order to convert the technology matrix into monetary matrix, we construct a price matrix for each flow in matrix $A$ (4), $P_{11} = P_{m1}$ stand for price for each flows in system.

$$P = \begin{bmatrix} p_{11} & p_{11} & p_{11} & p_{11} & \cdots \\ p_{21} & p_{21} & p_{21} & p_{21} & \cdots \\ p_{31} & p_{31} & p_{31} & p_{31} & \cdots \\ p_{41} & p_{41} & p_{41} & p_{41} & \cdots \\ p_{51} & p_{51} & p_{51} & p_{51} & \cdots \\ p_{61} & p_{61} & p_{61} & p_{61} & \cdots \\ p_{71} & p_{71} & p_{71} & p_{71} & \cdots \\ p_{81} & p_{81} & p_{81} & p_{81} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \\ p_{n1} & \cdots & \cdots & \cdots & p_{n1} \end{bmatrix}$$

The monetary matrix $A_m$ can be constructed by applying the Hadamard product (Deng et al. 2013) as (5).

$$A_m = A \circ C$$

Considering the different time profile of the different flows in the system, the discounting for each flow should be applied with a related timespan. A discounting matrix $D$ is constructed as (6). Where $q=1/(1+r)$, $r$ is the interest rate, $t_n$ is time of process. In order to calculate the total monetary flow for each units. A summation matrix $S$ is defined as $S=(1,1,1,\cdots,1)^T_{m \times 1}$, the number of 1 is equal to the number of rows in matrix $A$. 

$$A_m = A \circ C$$

151
The matrix-based LCC is defined as:

\[
D = \begin{bmatrix}
q^1 & q^{t_1+t_2} & \cdots & q^{t_1+t_2+\cdots+t_r}
q^2 & q^{t_1+t_2} & \cdots & q^{t_1+t_2+\cdots+t_r} \\
\vdots & \vdots & \ddots & \vdots \\
q^n & q^{t_1+t_2} & \cdots & q^{t_1+t_2+\cdots+t_r}
\end{bmatrix}_{m \times n}
\] (6)

The matrix-based LCC is defined as:

\[
mLCC = (A_m \circ D)^T \times S_{m \times 1}
\] (7)

**Results and Discussion**

The result of mLCC for this study should contain \( n \) rows and one column. Each element of the matrix represents the total cost/benefit of each unit (pre-farm phase, feed production on farm phase, animal phase, waste management phase, and other possible processes), considering the timespan of discounting an effect on each flow in one unit.

With the development of financial systems for monetization of emission, the emission cost can be easily integrated into mLCC, so the method can potentially be developed as a full environmental LCC with consideration of discounting on each flow in the system.

**Conclusions**

Compared with cost benefit analysis, the mLCC method is more compatible with the system boundary defined by LCA, which focuses on a full or economic life cycle. This also remedies the flaw in environmental LCC, which does not consider the timespan of discounting effects on each flow in the system.

**Acknowledgements**

This work is funded by Smart Integrated Livestock Farming (SILF) project, under ERA-NET scheme “ICT-AGRI”.

**References**


WATER REQUIRED FOR GRASS GROWTH ON IRISH DAIRY FARMS

Eleanor Murphy¹, Tomas Curran², Nicholas Holden² and John Upton¹

¹Animal & Grassland Research and Innovation Centre, Teagasc Moorepark Fermoy, Co. Cork, Ireland,
²Department of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland

Abstract

With the abolition of milk quotas in 2015 throughout Europe and government strategies such as Food Harvest 2020 which aims for a 50% rise in milk production through sustainable expansion there will invariably be increased pressure on freshwater resources on both a national and international scale. Quantifying the volumes of water used in the production of agricultural products is an important metric of the sustainability of future food production. Water consumed for forage production makes up a large proportion of the water demand for milk production. Irish milk production is the 10th largest dairy exporter in the world and is largely a rain-fed pasture based system. As a consequence of exporting dairy products there is also an export of ‘embedded’ water in the form of rainfall. This study quantified the volumes of rainwater used to grow grass and subsequently exported from the farm in the form of milk over 24 study farms. The rain-fed pasture based milk production systems in this study used 38% of available rain water. The utilisation of rain water which is plentiful in Ireland and available at a low opportunity cost to produce milk demonstrates the sustainability of milk production in Ireland.

Introduction

A lack of freshwater resources around the world are becoming increasingly concerning issues for many nations. Due to increased populations and along with economic prosperity, demand for the resources has rapidly increased. In hand with this growing demand, freshwater resource availability is predicted to be affected by global warming due to changes in the hydrological cycle’s activity which is anticipated to cause an overall alteration in worldwide rainfall events and patterns (Ambec et al., 2013). Agricultural practices are the highest consumers of freshwater worldwide, accounting for 70% of the global freshwater usage (UNEP, 2007) In terms of water resources, Irish agriculture does not suffer water shortages or droughts due to the nature of Ireland’s temperate maritime climate. On a global scale water availability is limited, and increased knowledge to improve sustainability or reduce consumption of water for production will improve the marketability of Irish dairy exports on the international markets (DAFM, 2010). The objective of this study was to quantify the rainfall water resources that are embedded in Irish milk production.

Water resources can be divided up into green and blue water. Rain-fed crop production consumes green water which is defined as water stored in the soil from precipitation. Irrigated crop production consumes blue water which refers to the water stored in rivers, lakes and aquifers. Irish milk production is largely a rain-fed pasture based system and is the 10th largest dairy exporter in the world (DAFM, 2012). As a consequence of exporting dairy products there is also an export of ‘embedded’ water. Water consumed through forage production makes up 94% of the water footprint of milk production (Mekonnen and Hoekstra, 2012). As demand for water resources increases due to increased food production,
population growth and climate change it is important to quantify the volumes of water that are embedded in dairy products in order to ensure sustainable production.

Material and Methods

Data collected included, climatic data, soil type, imported concentrate and forages, herd size and milk production from 24 specialised Irish dairy farms from May 2012 to April 2013. Farms were selected from a database of advisory clients within Teagasc. Selection criteria included availability of farm data and an ability and willingness of the farmer to collect and maintain accurate data. Milk production data were sourced from the Irish Cattle Breeding Federation records. Rainfall data were sourced from Met Eireann meteorological stations nearest to each farm. Annual grass and silage utilisation on each farm was modelled with the Grass Calculator (Teagasc, 2011) using the difference between the net energy in units of feed for lactation (UFL), between external supplements (concentrates and forages) and the net energy demands of farm stock (O'Mara, 1996). This approach was also utilised by Mihailescu et al. (2014) to model grass growth over 21 Irish dairy farms. It was assumed that 1 UFL equates to 1 kg dry matter of grass. It was assumed that 85% of the grass grown was utilised.

The volume of green water required for grass cultivation was computed using grass yield data, soil site specific data and climate data using the method described by De Boer et al. (2013). Climatic data from Met Eireann was used to compute ETo for each study farm. ETo is the evapotranspiration of the reference crop, grass, in this case ETo can also be understood as the potential evapotranspiration (ETp) for grass cultivation (Allen et al., 1998). The actual evapotranspiration (Eta, mm/ha) required from the actual yield of grass derived from the Teagasc Grass Calculator was then quantified from the relationship between water supply and crop yield described by Doorenbos and Kassam (1979):

\[
Eta = -((1 - Ya/Yp)/ky - 1) \times ETp
\]

Where Ya is the actual crop yield per hectare, Yp is the potential crop yield per hectare, ky is the yield response factor, which is crop-specific and describes the relationship between evapotranspiration deficit and yield reduction, ETp is the potential ET requirement (mm/ha) of the crop. The potential crop yield Yp was derived from the Agro- Ecological Zone method (Doorenbos and Kassam, 1979). Eta (mm/ha) is the actual green water (rainfall) consumed to grow the grass used on the study farms over the study period.

Results and Discussion

Average milk production per farm was 516,463 litres. The milk output on the study farms was greater than the national average farms for 2012. Average farm size was 69 hectares while the national average farm size was 57 hectares. The study farms therefore, represent larger than average dairy farms, indicative of future farm sizes, a result of farm expansion prior to the milk quota abolition in 2015. The average volume of green water required for the growth of grass was 286,082m³/farm/year (range 117,860 – 435,583m³). The average volume of water available through rainfall occurring on the farms was 751,514m³/farm/year (348,106 – 1,177,576 m³).
Table 1. Summary of 24 study farms compared to national average farm description.

<table>
<thead>
<tr>
<th>Description</th>
<th>Min.</th>
<th>Mean</th>
<th>Max</th>
<th>National Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm Area (Ha)</td>
<td>32</td>
<td>69</td>
<td>108</td>
<td>57</td>
</tr>
<tr>
<td>Milk Yield (L)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>258,663</td>
<td>516,463</td>
<td>883,365</td>
<td>316,000</td>
</tr>
<tr>
<td>Grass grown (T DM/farm)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>222</td>
<td>550</td>
<td>834</td>
<td>627</td>
</tr>
<tr>
<td>Rainfall (m&lt;sup&gt;3&lt;/sup&gt;/Farm)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>348,106</td>
<td>751,514</td>
<td>1,177,576</td>
<td>622,440</td>
</tr>
<tr>
<td>GWR&lt;sup&gt;d&lt;/sup&gt; (m&lt;sup&gt;3&lt;/sup&gt;/Farm)</td>
<td>117,860</td>
<td>286,082</td>
<td>435,583</td>
<td>311,429</td>
</tr>
</tbody>
</table>

<sup>a</sup> 000’s litres; <sup>b</sup> Tonnes of dry matter grass grown per farm; <sup>c</sup> cubic meters rainfall over farm area; <sup>d</sup> Grass water requirement for growth per farm.

The water required for grass growth consumed on average 38% of the rainfall occurring on the farms. This green water when exported in the form of dairy products could be considered as a national water loss; referring to the fact that water used for producing dairy products which are then exported is not available for domestic or industrial purposes. Green water cannot be easily re-allocated to other uses besides natural vegetation or alternative rain-fed crops, hence the use of green water in milk production takes advantage of this readily available resource. Of the dairy products exported in 2012, 38% were to international markets including South-East Asia and the Middle East (DAFM, 2012). These areas are already water stressed. By importing water embedded in agricultural commodities they can ‘save’ water by outsourcing milk production to a water rich country. As well as the consideration of rainwater as a resource it is also important to consider the natural conditions that exist in Ireland for the growth of grass. The Irish weather and soil types allow an extended grazing season which gives a competitive advantage over other countries and is essential in the output and viability of dairy farming in Ireland (Shalloo et al., 2004). Grassland only covers one fifth of all land in the EU whereas in Ireland, the majority (75%) of the country is covered in grassland, the highest percentage area of the member states in the EU (CSO, 2013). The utilisation of grass in food production systems is critical as it is a non-human edible crop which is converted into a human edible product in the form of dairy and meat when digested by ruminants on pasture based dairy systems. This again highlights the advantage that Irish grass-based dairy systems have over other systems that may not have such resources readily available to them.

Conclusions

The rain-fed pasture based milk production systems in this study used 38% of available green water. The utilisation of rain water which is plentiful in Ireland and readily available at a low opportunity cost to produce milk demonstrates the sustainability of milk production in pasture-based milk production systems in Ireland.
**Acknowledgements**
The authors acknowledge the support of the Carbery Greener Dairy Farms project.

**References**
Minimisation of wasted food has the potential to reduce the negative environmental impact of food chain inefficiencies. This work identified two scenarios for Ireland (i) wasted food and residue management for 2010 and (ii) a future scenario based on wasted food minimisation and residue management. The environmental footprints for the two scenarios were quantified and included global warming, eutrophication and acidification potential impacts. It was found that when wasted food is minimised and the residue composted (scenario ii) the potential environmental saving could be quantified at 3 million tonnes of CO$_2$e, 25 thousand tonnes of Pe, and 86 thousand tonnes of SO$_2$e per annum. With the consequence that minimising wasted food would allow an additional 1.46 million people to be fed or make available 730,000 ha of land.

**Introduction**

The minimisation of waste is a fundamental goal of EU policy, Directive 2008/98/EC, which subsequently trickles down to national policy. Food waste minimisation will require efficiency interventions along the whole food chain from production to consumption and must include producers, retailers and consumers. Technical and non-technical interventions are required to improve efficiencies which include changing human habits, sensor technology and data optimisation for decision making. However, not all food waste, as it is commonly known can be reduced. Oldfield and Holden (2015) suggest the use of different terminology when referring to anthropogenic organic waste, proposing three terms to differentiate between types: (i) ‘wasted food/product’ which refers to an item that has been mismanaged, (ii) ‘residue’ to describe those materials that are unavoidable, not consumable for their primary purpose, but can be utilised for an alternative purpose and (iii) ‘waste’ which should be strictly used to described those materials that are not utilisable and are disposed of in the biosphere sink. Life cycle assessment (LCA) estimates the potential environmental impact of a product, process or service over its entire life from cradle to grave and has been used to evaluate waste management systems at a meta, macro, meso and micro level (Andersen et al. 2012; Khoo et al. 2010; Saer et al. 2013; Bernstad and la Cour Jansen 2012. Traditionally, the upstream burden of waste has not been accounted for in LCAs of waste management systems (Oldfield and Holden, 2015), potentially resulting in sub-system optimisation. Therefore when carrying out an LCA of a system that uses wasted food or residue as a resource, the upstream burden should be included. In Ireland, approximately 1,051,000 tonnes of wasted food and residue was produced in 2010 (CSO, 2012). The objective of this study was to calculate the potential environmental saving due to the minimisation of wasted food in Ireland using an LCA approach.

**Methodology**

This research was a case study, using Irish data, which estimated the potential environmental saving due to wasted food minimisation. Two scenarios for Ireland (i) wasted food and residue management for 2010 and (ii) a future scenario based on wasted food minimisation and improved residue management. The potential environmental saving was calculated using an LCA model of compost with avoided burdens and included upstream impacts associated with food production. Landfill and fertiliser production were also modelled. GaBi 6 software was used throughout.
**LCA model**

Wasted food and residue requires management and can be processed through treatment technologies. The LCA model used in this study was constructed using secondary data from peer-reviewed journals and followed the four-stage LCA modelling process that is prescribed by ISO LCA methodology (2006a/b). Three impact categories were included, global warming potential (Kg CO$_2$e), eutrophication potential (kg Pe) and acidification potential (kg SO$_2$e), and the characterisation method CML 2001 was used (Guinee et al. 2002). The model assumed that wasted food and residue either go to landfill or in-vessel composting, with the later, subsequently being used in agriculture and avoiding the use of mineral fertiliser, and sequestering carbon.

In 2010, it was calculated that 269,000 tonnes of organic material was composted (Rx3, 2012). The percentage that was wasted food and residue was not presented, so it was assumed to be 50%, with the remaining 50% being green waste and thus not captured in this analysis. Therefore we calculated that in 2010, 134,500 tonnes of wasted food and residue was composted with the remaining 916,500 tonnes being sent to landfill with no energy recovery (illustrated as ‘2010 scenario’ in figure 1). This was then compared to the ‘waste minimisation scenario’ (Figure 2).

![Figure 1: 2010 Scenario](image)

![Figure 2: Waste minimisation scenario](image)

**Wasted food minimisation**

In 2010, approximately 3,503,333 tonnes of food was produced in Ireland (back calculated using 30% of food wasted, EPA, 2014a), with thirty percent of this not consumed and wasted (Figure 1). This consisted of wasted food and residue (1,051,000 Tonnes). Of this 30%, approximately 80% (840,800 tonnes) was avoidable (wasted food), with the remaining 20% (210,200 tonnes) being unavoidable (residue), consisting of materials such as chicken carcasses and orange peel.

This study assumed that twenty percent of the original thirty percent of wasted food was unavoidable and was therefore a residue

- Total residue = old efficiency (0.3) x residue (0.2) = 0.06.

It is not realistic to expect that the food production and consumption chain could become one hundred percent efficient with no losses. An additional four percent of wasted food due to inefficiencies in the food production and consumption supply chain was therefore added.
New residue and wasted food = residue (0.06) + wasted food (0.04) = 0.1 (Figure 2 - part c)

An increase in the efficiency of the food production and consumption supply chain, hypothetically, resulted in a decrease in the amount of food that would need to be produced (Figure 2) to meet the food demand. It was assumed that food demand does not increase, therefore the amount of food that would need to be produced, including the new figure for residue and wasted food (0.1) was calculated as:

- Food consumed (2,452,333 tonnes) / 0.9 (1-0.1) = 2,724,814 tonnes of food that would need to be produced

- Food production avoided = food produced (3,503,333 tonnes) – new amount of food produced (2,724,814 tonnes) = 778,518 tonnes avoided (figure 2 – part f)

The new amount of food that would need to be produced would result in a different amount of residue and wasted food, this was calculated as:

- Amount of Residue and wasted food = New amount of food produced (2,724,814 tonnes) x 0.1 = 272,481 tonnes per annum (figure 2 – part e)

**Results**

This analysis showed that waste minimisation would lead to a significant reduction in environmental impact in all three impact categories (figure 3a-c). Eutrophication potential reduction was shown to be reduced by 25 thousand tonnes of Phosphorus, whilst the acidification potential reduction was quantified at 86 thousand tonnes of Sulphur Dioxide per annum. It was quantified that the global warming potential reduction would be approximately 7 million tonnes of CO$_2$e per annum from the 2010 level. This is the equivalent to reducing the annual transport emissions by 50% in Ireland (estimated at 14 million tonnes per annum, EPA 2013b). The main reduction in the environmental impact came from less food production being required to meet the food demand, a direct result of reducing food chain inefficiencies.

**Discussion**

The potential environmental saving from food waste minimisation was large enough to warrant closer inspection. Compost was used as the treatment option as it is the most commonly found recovery technology for food waste in Ireland (Rx3, 2012). Other technologies, such as pyrolysis and anaerobic digestion may offer larger savings and should be assessed. The direct consequence of food chain efficiency increase would be that 1.46 million people could be fed in Ireland (Kastner et al. 2012) or 300,000 ha could be made available for other uses globally.

In order for minimisation to occur change is necessary, a method to identify opportunities along the supply chain would be to use ‘transitional thinking’ analysis which looks at the outcomes of
developments at the micro, meso and macro level (Kemp et al. 2012). Niches must be identified, such as new technology or new practice, which influence the regime (meso) and ultimately changes the landscape (macro). Niches, are occurring in food waste minimisation in Ireland, such as foodcloud, an app that facilitates the diversion of food nearing its use by date to charities that distribute to those in food poverty. However, for the amount of wasted food minimisation shown above to be realised many more niches are required along the food production supply chain, be it, consumer, producer or retailer initiated.

Conclusions and recommendations

Wasted food has a significant negative impact on the environment, its minimisation would result in a substantial reduction in global warming, eutrophication and acidification potential. If wasted food minimisation is to be realised a large number of niche interventions need to be identified and implemented along the food production and consumption supply chain. To further explore the potential environmental saving in residue management other technologies, such as pyrolysis and anaerobic digestion should be considered to deal with the recovery of valuable substance.

Acknowledgements

This research is funded by the Irish Research Council under the Government of Ireland scheme.

References


VISUAL SOIL STRUCTURE ASSESSMENT OF THE DAIRY UNIT AT UCD LYONS RESEARCH FARM

Dáire McKiernan, Jeremy Emmet-Booth and Nicholas M. Holden
UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.

Abstract

Visual methods of assessing soil structure provide a cheap, quick and semi-quantitative method of assessing soil structural quality. Techniques such as Visual Evaluation of Soil Structure (VESS) have been used in both tillage and grassland settings. Some visual methods require specific knowledge and are more time consuming compared to the versatile VESS method. This tool can be used to manage the productivity of agricultural soils. Both visual soil structure and overall soil quality, using laboratory analysis, will be assessed on the dairy unit of UCD Lyons Research Farm.

Introduction

Soil structure is vitally important to the production potential of grassland in Ireland. It is imperative that soil degradation and the effects of management practices on soil quality are assessed in as practical a manner as possible (Askari et al., 2014). Visual methods have been used to determine the soil structural quality (SQ) of both tillage and grassland. Laboratory analysis of soil can be time consuming and expensive due to the large volume of samples (Ball, 2007) and therefore Visual Evaluation of Soil Structural (VESS) is a preferable method. VESS provides a semi-quantitative method of assessing SQ. It was developed by Ball et al. (2007) and later modified by Guimaraes et al. (2011). It is a cheap and easily conducted method of soil assessment which does not require specific knowledge and therefore can be carried out by consultants, scientists and farmers. VESS involves removing a block of soil using a spade and breaking it up manually along natural fractures in the soil. The aggregates are then scored between SQ 1 (good soil structure) and SQ 5 (poor soil structure) using a visual key.

Visual assessment methods have been in use since the development of the Peerlkamp test (Peerlkamp, 1959) and a number of similar methods have been developed. Shepherd (2009) developed the Visual Soil Assessment (VSA) which involves a drop shatter test with aggregates being sorted and assessed according to reference photographs. ‘Profil cultural’ examines the impact of tillage on soil structure in arable land (Peigné et al., 2013). This method requires specific knowledge, time and effort and is therefore unsuitable for general use compared to other more versatile methods.

Visual methods of assessing soil structure have been open to criticism due to the potential for subjectivity. However, a number of studies have shown that they are in fact reliable methods and the same results can be obtained by users with varying knowledge of soil science (Mueller et al., 2013). Mueller et al. (2009) also showed how the soil quality results from VESS correlate well with crop yield.

The aim of this study is to assess the soil structural quality of the dairy unit at UCD Lyons Research Farm using Visual Evaluation of Soil Structure (VESS).

Materials and Methods

Prior to all field and laboratory assessment, the farming practices which have been carried out on the dairy enterprise will be collected from the farm manager. This will provide information on the management intensities such as livestock unit/ha, fertilizer inputs, age of sward and whether it is used for grazing purposes or for silage. Each management trait is classified into various intensity levels as listed by Cui et al. (2014):
### Figure 1. Values for management intensity scoring for nitrogen use, frequency of reseeding and stocking rate

<table>
<thead>
<tr>
<th>Score</th>
<th>N Use (kg/ha)</th>
<th>Reseeding (yr)</th>
<th>Livestock Unit/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-43</td>
<td>≥20</td>
<td>&lt;1.5</td>
</tr>
<tr>
<td>2</td>
<td>43-129</td>
<td>10-20</td>
<td>1.5-2.5</td>
</tr>
<tr>
<td>3</td>
<td>≥129</td>
<td>0-10</td>
<td>≥2.5</td>
</tr>
</tbody>
</table>

As VESS is a semi-quantitative method it will be used in tandem with laboratory analysis to assess soil structural quality. The method is carried out as described by Guimaraes et al (2011). The VESS method requires a section of soil to be removed using a spade with dimensions of 25 cm depth, 10 cm thick and 20 cm wide. The various layers are noted. The block of extracted soil is then placed on a plastic tray where it is described, and then manually broken up along the natural fracture lines. Exposed aggregates can be then further broken up. Various criteria are assessed including aggregate size, shape, strength, porosity, presence of roots, colour along with the effort required to break up the aggregates. A scorecard is used to apply an SQ score for each of the layers identified. This scorecard makes comparisons to reference photographs and ranges from SQ 1 (good soil structure) to SQ 5 (poor soil structure). Following this analysis, the final score for each sample is calculated by multiplying the score of each layer by its thickness and dividing the product by the overall depth. A minor disadvantage of this method is that it can only be carried out when suitable soil moisture conditions occur.

Laboratory analysis will use 1 kg of soil from each site sampled along with a soil core of 100 cm³, which will be analysed within 48 hours. Bulk density, moisture content, total nitrogen and total carbon are to be measured with soil porosity being calculated from bulk density by assuming a particle density of 2.65 g/cm³ and utilising the following equation (Cui et al, 2014):

\[
\phi = 1 - \left( \frac{\rho_b}{\rho_p} \right)
\]

**Statistical Analysis**

The data is to be analysed using SPSS v. 18.0 (SPSS Inc.) with correlations between parameters to be calculated using Pearson’s Product Moment Correlation Coefficient. One-way ANOVA is to be used to test for difference in SQ by management intensity.

**Results**

VESS is to be used to determine the SQ between fields of the dairy unit at UCD Lyons Research Farm. It is expected that the method will show differences in the various management techniques between fields and this method will result in accurate representations of SQ. It is predicted that it will be possible to validate these results by comparing them with the variation in the various recorded physical soil parameters. Bulk density was found by Guimareas et al (2013) to relate well with soil bulk density.

It is expected that the soils sampled will not be of SQ 4 or SQ5. This is due to the assumption that the typical management intensities utilised on Irish dairy farms do not cause damage to the detriment of structural quality. As Askari et al (2014) showed, it is expected that frequency of reseeding and the concentrations of carbon and nitrogen in the soil which will indicate good soil structure.

**Conclusion**

Soil structural quality is essential for grass production and to ensure management techniques are not having a detrimental effect on this, a cheap and effective method of analysing soil quality needs to be utilised. It might be expected that soil degradation could occur due to high intensity management practices seen on dairy farms. This may have a negative impact on sustainable grassland productivity.
It can be concluded that visual monitoring of soil structural quality has the ability to provide a simple and effective method of rating SQ.

This study aims to show the utility of VESS at a farm-level and demonstrate its reliability for predicting soil structural quality under dairy management practices.

References


THE INFULENCE OF REGIONAL CLIMATE AND SOIL DRAINAGE ON GLOBAL WARMING POTENTIAL OF IRISH DAIRY FARMS

Pooja Sharma¹, James Humphreys², Nicholas M. Holden¹
¹UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.
²Teagasc Livestock Systems Research Department, Animal and Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland.

Abstract

Due to the significant variation in climate and soil drainage in Ireland there is great variation in the productivity of the Irish dairy farms. This work involves system modelling using Dairy_sim, which captures the effect of weather interaction and soil drainage on the management of grass based production systems, and LCA modelling to evaluate the environmental impacts of simulated dairy farms at various locations in Ireland.

Introduction

There were 17,000 dairy farmers producing 300,000 litres of milk in Ireland in 2014 (Irish Farmers Association 2014). After abolition of the milk quota in 2015, farmers will be able to pursue efficiencies and increase milk supply by 50% by 2020. This increase in productivity should not be allowed to affect the environment.

There is a significant variation of climate and soil in Ireland. In all climate zones, inter-annual variation in seasonal weather is significant and also the weather variation differs significantly between soil types. Thus, the average values in Ireland do not reflect reality at any moment in time. The effect of weather conditions has important implications on management systems for the dairy production (Fitzgerald et al., 2005). There is also a significant regional agro-climatic variation in Ireland (Holden and Brereton 2004). Adjustments to stocking rate, output per cow, nitrogen management and quantity of concentrates imported on dairy farms are used to match farm to environment. Dairy_sim was programmed to simulate the tactics that might be used to respond these variations. Dairy_sim assesses the interaction between climate and management in spring-calving milk production systems based on the grazing of grass pastures.

Dairy farms are found on both well and poorly drained soils in most parts of Ireland (Fitzgerald et al., 2009). The profitability of a spring-calving, grass-based milk production system on a site with lower rainfall and free draining soil type is much greater than on a high rainfall and heavy clay soil site (Shalloo et al., 2004). Dairy farms on well-drained soils outperformed their equivalents on poorly-drained soils and are able to sustain higher stocking rates by 0.6-0.9 cows/ha (Fitzgerald et al., 2008). There are also large differences in the housing and forage requirements between well and poorly drained soils (Fitzgerald et al., 2008).

Life Cycle Analysis is used to understand the environmental impact of milk production (Yan et al., 2013b). It indicates the environmental burden throughout the life cycle of a product (ISO 2006). A total emission of 1.50 kg CO₂eq kg⁻¹ yr⁻¹ (energy corrected milk) from the average Irish milk production system was calculated by Casey and Holden (2005).

The objective of this study is to estimate and compare the sensitivity of global warming potential of dairy farms in Ireland to regional variations in climate and soil drainage.
Materials and Methods

The overall study is divided into two parts, first is Dairy_Sim simulation and second is Life Cycle Assessment. Inputs from varies sources will be collected and results will be derived as shown in the Figure 1.

![Figure 1. A framework model showing the overall approach of the study](image)

In the first part of the study, Dairy_sim will be used to obtain the theoretical ideal farm for selected locations by adjusting management parameters to find an optimum management system. An ideal farm is one which has a balance between silage production and feed demand, minimum number of days of winter housing and maintains grass availability in grazing areas of farms, thus limiting the probability of need to supplement the grazing herds with silage or concentrates (Fitzgerald et al., 2005). There are three components in the simulator: a grass herbage growth model, an intake and grazing behaviour model and a nutritional energy demand model. The data required for Dairy_sim are: farm location, farm layout, herd data, farm management and daily climate data for various locations (mean, max and min temperatures, radiation, precipitation and evapotranspiration).

The model will be tested using daily meteorological data (1981-2010) and system simulation will be initially parameterised based on the data shown in Table 1. The stocking rate, fertilizer applications, silage management and other parameters will be adjusted to find the geographically optimised system. The effects of regional variations in climate on system management will be compared for well-, moderately- and poorly-drained soils. Analysis of regional variation will be done using 30 year daily weather data collected by Met Eireann. The example locations are: Mullingar, Birr, Gurteen, Cork airport, Dublin airport, Shannon airport, Knock airport, Valentia Observatory and Malin Head.

Table 1. Baseline management input data for Dairy_sim (Fitzgerald et al., 2005)

<table>
<thead>
<tr>
<th>S.No</th>
<th>Input data</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Paddocks and farm area</td>
<td>20</td>
</tr>
<tr>
<td>2.</td>
<td>Stocking rate</td>
<td>2.6 cow/ha</td>
</tr>
<tr>
<td>3.</td>
<td>Milk yield</td>
<td>6400 l/cow/yr</td>
</tr>
<tr>
<td>4.</td>
<td>Live weight</td>
<td>610 kg</td>
</tr>
<tr>
<td>5.</td>
<td>Total Nitrogen applied</td>
<td>360 kg N/ha</td>
</tr>
<tr>
<td>6.</td>
<td>Area of farm for 1st and 2nd cut silage</td>
<td>9/7 ha</td>
</tr>
<tr>
<td>7.</td>
<td>Date of closing, 1st silage cut</td>
<td>1/4</td>
</tr>
<tr>
<td>8.</td>
<td>Date of closing 2nd silage cut</td>
<td>28/5</td>
</tr>
<tr>
<td>9.</td>
<td>Cut 1</td>
<td>27/5</td>
</tr>
<tr>
<td>10.</td>
<td>Cut 2</td>
<td>15/7</td>
</tr>
</tbody>
</table>
The second part of the study involves LCA modelling of optimum dairy production systems derived from *Dairy_sim*. The model will be prepared in GaBi software. LCA has a four-stage procedure: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation (ISO 2006a). The goal of the study is the same as the main objective of the study. The functional unit to which all the inputs and outputs relates will be considered as “1 kg energy corrected milk (ECM)”: kg ECM = kg milk x (0.25 + 0.122 x fat% + 0.077 x Protein %) (Sjaunja et al., 1990). The system boundary for the study will be “cradle-to-farm-gate” and will include on-farm processes and off-farm production of feed, fertilizers, energy and their transportation. Capital goods like machinery and buildings will be excluded from the system. There are two outputs from the dairy system one is milk and the other is meat. Biophysical methods will be used to allocate the emissions. Some of the data required for LCI will be taken from *Dairy_sim* outputs and other input/output data for each process will be collected from Ecoinvent-Gabi databases and published data from previous studies. Apart from global warming potential other impact categories such as acidification, eutrophication and energy use will also be evaluated. Significant issues, sensitivity evaluation and conclusions will be drawn in the interpretation phase.

**Results and Discussion**

As this research is in its early stages and there are no verified results, it is difficult to predict the results of the study. However, from previous studies, poorly drained soils have less milk production than well drained soils with the same area of farm land, so we can say the global warming potential of these farms should be higher than the well-drained farms as GWP is a function of milk output.

**Conclusions**

For this study a comparison of impacts of dairy farms in various locations with different climatic and soil conditions will be evaluated. The evaluation of the variability of environmental impacts of dairy production systems in Ireland will inform management decisions on land use management changes. An impact assessment comparison of the farms on well-moderately and poorly drained soils will be prepared for analysis. Furthermore, the study will assess the improvement in productivity of dairy farms on wet soils by introducing artificial drainage and life cycle assessment for the same.

**Acknowledgements**

This research has been undertaken with the financial support of Department of Agriculture, Food and the Marine.

**References**


THE APPLICATION OF NIR AND MIR FOR THE PREDICTION OF SOIL PHOSPHORUS DYNAMICS IN AGRICULTURAL SOILS

Kathleen Dunne¹², Nicholas M. Holden¹ and Karen Daly²
¹UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland.
²Environment, Soils and Land Use Department, Teagasc, Johnstown Castle, Co. Wexford, Ireland.

Abstract

Soil fertility and soil quality are important for agricultural sustainability. These parameters are monitored by testing for indicators such as: Morgan’s Phosphorus (P), pH, % OM, Al, Fe and Ca. There is also a requirement to test soil for P, under The Nitrates Directive, which protects water quality. However, traditional wet chemical methods can be time consuming, expensive and can generate a large amount of chemical waste. This project, which has just commenced, will explore the application of diffuse reflectance infrared Fourier transform (DRIFT) spectroscopy, in combination with chemometrics, for the prediction of soil fertility and quality indicators, specifically, P buffering and P sorption capacities. It is hoped this technique will act as a surrogate for traditional time consuming, expensive and waste generating methods. For the first step, two preliminary experiments are being undertaken to better understand sample preparation requirements in the laboratory and to determine the spectral region most appropriate for phosphorus dynamic analysis in agricultural soils. The chemical analysis focuses on extractable Al, total Fe and extractable Ca, because P cannot be directly analysed using IR spectroscopy. These three elements are correlated with phosphorus dynamics in soil.

Introduction

Phosphorus can be one of the most limiting elements in crop production, so, mineral P fertilisers often need to be applied to agricultural soils to achieve optimal crop yield, however if amounts exceed crop requirements, this can have a negative environmental effect (Abdi et al. 2012). For this reason, P dynamics in agricultural soils must be monitored. In recent years, a large number of soil properties have been predicted using multivariate chemometric regression modelling, derived from reference soil data and UV, Vis, NIR and MIR spectra (Soriano-Disla et al. 2014). Soil analysis in this project focuses on elements such as: extractable Al, total Fe and extractable Ca. This is because P dynamics can be inferred from the analysis of these elements (Herlihy and McGrath 2007). The application of near infrared reflectance spectroscopy (NIRS) for analysis of environmental materials requires a calibration procedure using sophisticated statistical techniques, because the anharmonic overtones in this region make analysis of a complex matrix difficult. In contrast, the MIR region mostly relates to transitions between vibrational states of molecules with high molar absorptivity and the peaks of mid infrared reflectance spectroscopy (MIRS) are specific and sharp (Shao and He 2011). This raises the question of which spectral region is most suitable for the prediction of these elements in agricultural soils.

It is also important to consider the physical aspects of a soil sample before presentation to a spectrometer. This is because calibration performance in infrared spectroscopy can be affected by the physical presentation of the soil, such as size and shape of the particles (Chang et al. 2001, Nduwamungu et al. 2009).
The two experiments described in this paper aim to determine an appropriate sample preparation and the spectral region most appropriate for infrared spectroscopic analysis of phosphorus correlated elements, in agricultural soils.

Materials and methods

1. Determination of an appropriate sample preparation for infrared spectroscopic analyses of pasture soils

The aim of this experiment is to find if there are significant differences in the infrared spectra of samples with 4 different diameters of sample fineness when analysing for P correlated elements. Sixteen soil samples will be taken from the Irish Soil Information System archive, from 4 different soil associations to a depth of 100 mm. These samples are already air-dried and sieved using a 2 mm screen. The samples will be split, further ground and screened to 1.0, 0.5 and 0.2 mm. Absorbance \[ \log \left( \frac{1}{R} \right) \] of all soils (16 soil samples x 4 treatments = 64 soils of varying diameter) will be determined, in triplicate, in the appropriate infrared region for each of the following parameters; Al, Fe and Ca. There will be 192 analyses carried out. Each parameter (Al, Fe and Ca) will be analysed for significant difference in signal strength and precision between soil fineness treatments.

2. Determination of the spectral region most appropriate for analysis of Al, Fe and Ca in pasture soils

The aim of this experiment is to generate a spectral calibration from which concentrations of extractable Al, total Fe and extractable Ca, in unknown samples can be determined. These elements have a strong affinity for P in soil and can be used to infer P sorption capacities in grassland soil. The spectral region most appropriate for analysis of each element will be determined in tandem. This calibration will represent all horizons in each modal profile analysed, therefore, it can be used in the future to determine the appropriate horizon/depth for further P dynamic analysis in agricultural soils. Chemical data from the Irish Soil Information System archive (888 samples) will be filtered. This chemical data set was generated using traditional wet chemical methods. Two hundred modal profiles are represented in this data set, but only some of the profiles contain chemical data from all horizons. Profiles that contain sufficient chemical data from all horizons will be extracted. Absorbance \[ \log \left( \frac{1}{R} \right) \] of all the samples, with sufficient reference data, will be determined using a dual range infrared reflectance spectrometer, in the NIR, MIR and combined regions (NIR-MIR) of the spectrum. Software (The Unscrambler®) will then be used for chemometric analysis, looking for correlation between the reference data and the spectral data. The spectral region with the highest \( R^2 \) values will be determined as the region most appropriate for analysis of these elements. Using the region most appropriate for each elemental analysis, a spectral calibration will be generated, from which unknown samples can be analysed in the future.

Expected results and discussion

1. Determination of an appropriate sample preparation for infrared spectroscopic analyses of pasture soils

Qualitative peaks for exchangeable Al, total Fe and exchangeable Ca are expected to appear in the near and mid infrared regions of the spectrum (Abdi et al. 2012, Soriano-Disla et al. 2014). P dynamics (in particular, sorption) are correlated with these parameters (Amrani et al. 1999).

The variation of characteristic peaks by fineness is expected to be very small: expected standard deviation: \( \sim 0.02 \% \). The variation of signal strength at different soil diameters is also expected to be very small: expected standard deviation: \( \sim 0.02 \% \). These results would indicate that samples sieved to < 2 mm are the appropriate fineness for infrared spectroscopic
analyses of phosphorus dynamics in soil and that grinding to a smaller particle is not necessary for improved signal strength or precision (Nduwamungu et al. 2009).

Table 1. Results table from the determination of sample preparation experiment

<table>
<thead>
<tr>
<th>Particle fineness</th>
<th>Al Peaks (cm⁻¹)</th>
<th>Signal Strength (%) T</th>
<th>Fe Peaks (cm⁻¹)</th>
<th>Signal Strength (%) T</th>
<th>Ca Peaks (cm⁻¹)</th>
<th>Signal Strength (%) T</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 mm</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
</tr>
<tr>
<td>1.0 mm</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
</tr>
<tr>
<td>0.5 mm</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
</tr>
<tr>
<td>0.2 mm</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
<td>λ in NIR and MIR regions</td>
<td>Not yet known</td>
</tr>
</tbody>
</table>

Expected SD

<table>
<thead>
<tr>
<th>Al</th>
<th>Fe</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ 0.02 % (with 0.05 confidence interval)</td>
<td>~ 0.02 % (with 0.05 confidence interval)</td>
<td>~ 0.02 % (with 0.05 confidence interval)</td>
</tr>
<tr>
<td>~ 0.02 % (with 0.05 confidence interval)</td>
<td>~ 0.02 % (with 0.05 confidence interval)</td>
<td>~ 0.02 % (with 0.05 confidence interval)</td>
</tr>
</tbody>
</table>

λ, wavelength; MIR, mid infrared; NIR, near infrared; Peaks, characteristic peaks; SD, standard deviation; T, transmittance.

2. Determination of the spectral region most appropriate for analysis of Al, Fe and Ca in pasture soils

Successful correlation of reference data with a region of the spectrum (NIR, MIR or NIR-MIR) will be determined using $R^2$ values, where values closer to 1.0 have a greater correlation between reference data and spectral data, than smaller values.

Table 2. Correlation values ($R^2$ values) from spectral region experiment

<table>
<thead>
<tr>
<th>Al</th>
<th>Fe</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISIS profile number</td>
<td>ISIS profile number</td>
<td>ISIS profile number</td>
</tr>
</tbody>
</table>

|$R^2$ of ref data with spectral data in NIR | Not yet known | Not yet known | Not yet known |
|$R^2$ of ref data with spectral data in MIR | Not yet known | Not yet known | Not yet known |
|$R^2$ of ref data with spectral data in NIR-MIR | Not yet known | Not yet known | Not yet known |

Expected variation

|$R^2$ expected to be greatest in the MIR region | $R^2$ expected to be greatest in the MIR region | $R^2$ expected to be greatest in the MIR region |

ISIS, Irish Soil Information System; MIR, mid infrared; NIR, near infrared.

The following are guidelines that have been used to evaluate infrared spectroscopic calibrations for soil samples (Nduwamungu et al. 2009): Excellent: $R^2 > 0.95$; successful:
0.90 \leq R^2 \leq 0.95; \text{ moderately successful: } 0.80 \leq R^2 < 0.90; \text{ moderately useful: } 0.70 \leq R^2 < 0.80; \text{ and less reliable: } R^2 < 0.70.

R^2 \text{ values for extractable Al, total Fe and extractable Ca are expected to be greatest in the MIR region, indicating that the wet chemical laboratory data is correlating successfully with the MIR region of the spectrum and that this region is the most appropriate for infrared spectroscopic calibration of these elements.}

**Expected conclusions**

It is expected that samples sieved to < 2 mm will be the appropriate fineness for infrared spectroscopic analyses of phosphorus dynamics in soil. It is not expected that grinding to a finer soil particle will improve signal strength or precision (Nduwamungu *et al.* 2009).

It is expected that extractable Al, total Fe and extractable Ca will all have greater R^2 values in the MIR region, than the NIR region and that combined analysis (NIR-MIR) will have less reliable/poor correlation with reference data (Soriano-Disla *et al.* 2014). It is expected that MIR will be determined as the spectral region most appropriate for analysis of elements which infer dynamic phosphorus activity in pasture soils.

**Acknowledgements**

The authors would like to acknowledge funding from the Teagasc Walsh Fellowship Scheme.

**References**


SELECTION OF SUITABLE VISUAL SOIL EXAMINATION AND EVALUATION TECHNIQUES FOR USE IN IRISH GRASSLANDS

J. P. Emmet-Booth1, P. D. Forristal2, O. Fenton3 and N. M. Holden1
1UCD School of Biosystems Engineering, University College Dublin, Belfield, Dublin 4, Ireland
2Crop Science Department, Teagasc Oak Park, Carlow, Co. Carlow, Ireland
3Teagasc Environment Research Centre, Johnstown Castle, Co. Wexford, Ireland

Abstract

Visual soil examination and evaluation (VSEE) techniques have become internationally recognised as useful and robust methods for assessing soil physical quality. A number of different procedures exist. Research in Ireland indicated that certain techniques were effective, though suggested modifications to existing methods may be necessary. In order to identify VSEE techniques suited to general deployment in Ireland and thus worthy of further research, a theoretical selection was based on (1) conclusions made from a previous literature review, (2) Irish soil characteristics and (3) technique ease of use. It was concluded that the Visual Examination of Soil Structure (VESS), a version designed for subsoil assessment (the SubVESS Flowchart), and the Visual Soil Assessment (VSA) methods were the most suitable.

Introduction

Visual soil examination and evaluation (VSEE) techniques are semi-quantitative procedures for assessing soil physical quality (Mueller et al 2013). They require the visual and tactile assessment of soil with reference to manuals or in some cases, score sheets allowing numeric classification. Despite the simplicity of VSEE techniques, their utility has been increasingly recognised in international literature and practice (Ball et al 2013). Such procedures generally examine soil structure, a key property in overall soil quality (Mueller et al 2013). Indeed, previous research indicated that VSEE techniques were capable of not only indicating soil physical quality (Guimarães et al 2013) but also biochemical quality (Askari et al 2015). Additionally, unlike quantitative measurements, VSEE techniques require little equipment, little prior expertise to conduct or interpret, are quick to implement and generate immediate results (Ball et al. 2007). Such attributes make VSEE techniques accessible to a range of users, including farmers - an important aspect, as arguably farmers are key managers of soil resources. The application of VSEE techniques in Ireland is relatively limited, though research has demonstrated their utility on both grassland (Cui et al 2014) and arable (Askari et al 2013) soils, but suggested modifications may be necessary.

Over the last 60 years, a number of VSEE techniques have been described, a thorough review of which has been undertaken (Emmet-Booth et al 2015). These can be categorised as profile techniques and spade techniques (Mueller et al 2009), the former examine whole soil profiles, while the later examine up to 45 cm depth using a spade. Two spade techniques have been used in Ireland to date, the Visual Examination of Soil Structure (VESS) described by Ball et al (2007), later modified by Guimarães et al (2011) and the Visual Soil Assessment (VSA) procedure of Shepherd (2009), the later as part of Ph.D. research (Regan, 2010). Ireland has a temperate maritime climate (Keane and Sheridan 2004) with about 90 per cent of the agricultural area under pasture (O’Mara 2008) both leading to specific soil related characteristics.

The objective of this study was to build on conclusions made following a review of VSEE techniques in order to identify methods best suited to grassland soils and a range of users in Ireland.
Materials and Methods

Conclusions on different VSEE techniques identified and described as part of a previous literature review (Emmet-Booth et al 2015) were considered in relation to Irish soils. As correlations have been widely demonstrated between VSEE techniques and quantitative measurement of soil physical quality (Sonneveld et al 2014; Guimarães et al 2013), emphasis was placed on other factors such as the time required to conduct procedures, general ease of use, the requirement of prior knowledge for successful deployment and the final output, whether concise numeric scores or complex written descriptions.

Results and Discussion

The suitability of different profile and spade techniques is summarised in Table 1 and Table 2. Great variation between level of assessment and ease of application was noted. Profile methods require the excavation of soil pits by mechanical means but allow in-depth assessments of entire soil profiles, and as a result are more time consuming, thus limiting the potential for replication. However, the recently published SubVESS Flowchart (Ball et al 2015) appears less time consuming. It includes a simple score sheet and though may not provide the level of assessment as some other Profile techniques, offers a relatively straightforward procedure. The generation of numeric scores summarising soil structural conditions is desirable, allowing the rapid interpretation of results and aiding appropriate management decisions if required. Concise numeric scores also allow statistical analysis, useful for research. The SubVESS Flowchart satisfies this requirement, with a three-digit nominal score produced. Spade techniques are quicker to conduct, generally examining just topsoil but allow replication and greater spatial coverage. The widely utilised VESS (Ball et al 2007) and VSA (Shepherd 2009) procedures are among the quickest to conduct, while allowing sufficiently thorough assessments. Both procedures, which use simple scoring systems, are appropriate for grassland and arable soils, and are suitable for expert and non-expert users.

Table 1. The potential suitability and justification of Profile VSEE techniques for use in Ireland

<table>
<thead>
<tr>
<th>VSEE Technique</th>
<th>Suitability</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Le Profil Cultural</td>
<td>No</td>
<td>Despite providing an in-depth assessment, this is a time consuming method (1-3 hours) and is only applicable to arable soils. A prior knowledge of soil science is required, and a complex descriptive score sheet is finally generated.</td>
</tr>
<tr>
<td>Whole Profile Method</td>
<td>Maybe</td>
<td>The method provides an in-depth assessment and is suggested to be suitable to non-expert use after some training. No final numeric score is generated but it is suggested other scoring systems can be incorporated. The method takes between 20 and 40 minutes to conduct, after soil pit excavation.</td>
</tr>
<tr>
<td>SOILpak</td>
<td>Maybe</td>
<td>Originally designed for use on Vertisols and by cotton growers in Australia, the method has been modified for use on a range of soils under different management. It takes between 25 and 90 minutes to conduct, after soil pit excavation. A structure score is generated and the method is suitable for non-expert use. However, the manual supplied is complicated and poorly illustrated.</td>
</tr>
<tr>
<td>SubVESS Flowchart</td>
<td>Yes</td>
<td>The method appears straight-forward to conduct. A concise score sheet (Flowchart) aids efficient classification while the system is suitable for non-expert use with basic training. Numeric scores are generated for individual layers giving a holistic summary of structural condition. However, the three-digit nominal value may be difficult to handle statistically. The system can be used in conjunction with VESS (spade technique).</td>
</tr>
</tbody>
</table>

(Adapted from: Emmet-Booth et al 2015)
<table>
<thead>
<tr>
<th>VSEE Technique</th>
<th>Suitability</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Görbing Spade Diagnosis</td>
<td>No</td>
<td>A basic method on which later, more sophisticated methods are based. No final numeric score is generated.</td>
</tr>
<tr>
<td>Peerlkamp Method</td>
<td>No</td>
<td>A basic method on which later, more sophisticated methods are based. A ten scale score is used which is suggested to be open to subjectivity.</td>
</tr>
<tr>
<td>The Werner Method</td>
<td>No</td>
<td>Despite allowing an in-depth analysis, this method is time consuming, potentially limiting replication. A final five-digit string of numbers is generated which is difficult to interpret.</td>
</tr>
<tr>
<td>The Diez Method</td>
<td>Maybe</td>
<td>This technique can deal with apedal structures, an issue noted when examining soils in Ireland (Askari et al. 2013). However, it appears only suitable for use on arable soils while also only being available in German.</td>
</tr>
<tr>
<td>Extended Spade Diagnosis</td>
<td>No</td>
<td>A lack of published literature suggests this technique is not widely deployed. The procedure is a modified version of Görbing Spade Diagnosis.</td>
</tr>
<tr>
<td>Spade Analysis</td>
<td>No</td>
<td>The technique takes approximately one hour to conduct potentially limiting its replication.</td>
</tr>
<tr>
<td>Visual Soil Assessment (VSA)</td>
<td>Yes</td>
<td>This technique has been widely tested and deployed. It is capable of examining grassland and arable soils while generating a single, summarising numeric score. It is suggested that the whole procedure takes up to an hour though the structure test component takes roughly 20 minutes. Considered a multi-parametric system, with the assessment of multiple factors individually. The method includes a drop test (where a 20cm³ sample block is dropped from a height of 1 m, a maximum of three times) for the exposure of aggregates, which may limit subjectivity. Biological indicators (earthworms and rooting) are directly assessed unlike other methods, which indirectly examine these properties. A clear and illustrated operator manual is provided and the method is considered appropriate for non-expert use.</td>
</tr>
<tr>
<td>FAL Method</td>
<td>No</td>
<td>Despite providing an in-depth assessment, this technique is elaborate and requires the sieving of samples and computer calculations. A prior knowledge of soil science is required and takes up to 90 minutes to conduct, limiting its replication.</td>
</tr>
<tr>
<td>Soil Quality Scoring Procedure (SQSP)</td>
<td>No</td>
<td>This technique takes up to one hour to conduct, and deployment is sensitive to time of year. Previous research found that quantitative measures were not as strongly related to this method as other methods (VESS, VSA). A three number score is generated making it not as easy to interpret as other systems.</td>
</tr>
<tr>
<td>Visual Evaluation of Soil Structure (VESS)</td>
<td>Yes</td>
<td>The technique has been extensively tested (including in Ireland on arable and grassland soils). A very simple method, which takes roughly 15 minutes to conduct (allowing replication and wide spatial coverage) and generates a final numeric score. The method requires the exposure of aggregates by hand, which may be open to subjectivity. However it is suggested that this yields similar results as the VSA drop test (Guimarães et al. 2011). A detailed and illustrated operator scoring sheet is provided aiding efficient use.</td>
</tr>
<tr>
<td>Muencheberg Soil Quality Rating (M-SQR)</td>
<td>No</td>
<td>Useful in indicating the potential productivity of a soil over a wider area, this method is somewhat complicated with a number of component parts. The technique is not exclusively an in-field method and requires a prior knowledge of soil science to successfully conduct.</td>
</tr>
</tbody>
</table>

**Conclusion**

A diverse range of VSEE techniques have been developed, a limited number of which have been tested in Ireland. Following a theoretical review of different methods with consideration of requirements for their deployment in Ireland, it was concluded that for subsoil assessment, the SubVESS Flowchart was potentially the most suitable technique, and is worthy of further development and consideration.
investigation. For topsoil structure assessment, the VESS and VSA procedures were identified as most suitable, providing relatively quick, straight-forward evaluations while generating concise numeric summarising scores.

Acknowledgements
This work was funded by the Irish Department of Agriculture, Food and the Marine, Research Stimulus Fund (grant number 13S468). Advice from Mr T. Oldfield of University College Dublin was gratefully received.

References
Appendix 1
(Research projects in progress which have not been included in the Research Review)

Sweeney J and McDonnell K. Development of smart sensing for hybrid ad reactors (PhD). Science Foundation Ireland.

Rice P and Holden N. The role of allocation in the Carbon footprinting of dairy and beef systems (PhD). Research Stimulus Fund as administered by the Department of Agriculture, Food and the Marine.

Walsh J and Ward S. Carbon trading and management (PhD). Science Foundation Ireland under Grant Number 6C/CP/E001.

Donnelly-Swift R and Holden N. Monitoring of slurry application using remote sensing (PhD). STRIVE as administered by the Environmental Protection Agency.

O’Flynn M and McDonnell. Influence of harvest traffic on soil compaction, crops response and biomass yield in Miscanthus (PhD). Science Foundation Ireland.

Guth F and Ward s. Crop health (PhD). Brazilian Science without Boarders, CPNq.

Tuffy K and Holden N. Impact of artificial sub-surface drainagiage on pasture production, the length of the grazing season and the profitability of milk production on a heavy wet soil (PhD). Research Stimulus Fund as administered by the Department of Agriculture, Food and the Marine and Teagasc Walsh Fellowship.

Oldfield T and Holden N. The amount and value of nutrients in biological waste streams in Ireland (PhD). Irish Research Council under the Government of Ireland scheme.


Keena G and O’Donnell C. Improving the efficiency and sustainability of cheese ripening processes (MEngSc). Teagasc Walsh Fellowship Scheme.


Henihan L and O’Donnell C. Development of PAT tools for quality and safety improvement in dairy ingredient manufacture for infant formula (PhD). Food Institutional Research Measure (FIRM) administered by the Irish Department of Agriculture, Food and the Marine.


Zhang L, Zhang Z, Drummond L and Sun DW. Comparison of three desorption isotherm determination methods on by using microcrystalline cellulose (PhD). European Commission, 7th Framework Programme.
Appendix 2
Profiles of Postdoctoral Research Scholars only includes: Drs Devlin, Esquerre, Everard, Farrell, O’Brien, Riccioli, Walsh

Dr. Ger Devlin, BSc., PhD.


Project Leader: Dr. Kevin McDonnell

Abstract
The Irish government has undertaken to reduce national CO₂ emissions through a range of measures put out in their Biomass Action Plan and the National Renewable Energy Action Plan. The conversion of peat fired power plants to co-fire with renewable biomass is one of these. This work considers how the adoption of sweeping policies impact on other actors presently supplying or utilizing woody biomass resources for renewable electricity generation.

Background, Qualifications and Skills
Dr Ger Devlin obtained his primary degree in BSc. Applied Physics from Dublin City University (DCU) in 2001. He was awarded his PhD degree in Engineering from the Department of Biosystems Engineering, UCD in 2007. He is Ireland’s representative and management committee member on COST Action FP0902 - "Development and Harmonization of new operational research and assessment procedures for sustainable forest biomass supply (www.forestenergy.org)." He is also Ireland's first representative on the International Energy Association (IEA) Task 43 - "Biomass Feedstocks for Energy Markets." He currently has 56 publications that include 3 books, 1 book chapter, 1 Good Practice Guide in Timber Transport, 1 book Editor and 26 international peer review publications along with 3 technical report publications and 14 conference publications. He is reviewer for several peer review journals including Fuel Processing Technology, Transportation Research Part D, Journal of Transport Geography, International Journal of Forest Engineering, Journal of Forest Energy, Canadian Journal of Forest Research and ASABE to name a few. He is also the first Irish based Editorial board member on the International Journal of Forest Engineering.

Peer-reviewed Publications
Carlos Alberto Esquerre Fernandez, BSc, MSc, PhD

**Project title:** Development of optical imaging technologies to rapidly assess safety and quality of cereals (CerealScan)

**Project Leader:** Professor Colm P. O’Donnell and Shane Ward

**Abstract**

The overall goal of this project is to develop and validate on-line, non-destructive optical imaging technologies to rapidly assess safety and quality of cereals at critical processing stages post-harvest. This will reduce food safety risks and result in economic benefit to the cereal industry.

**Background, Qualifications and Skills**

My main research interests are application of sensor technology and chemometric analysis. The objective of my PhD at UCD was to develop spectroscopy and hyperspectral methods for early detection of physical damage in mushrooms. During this study I developed skills and knowledge in the areas of NIR spectroscopy, NIR hyperspectral imaging and chemometrics. Following the successful completion of my PhD I took up a position as Postdoctoral Researcher at UCD Biosystems Engineering (2010) where I focused on chemometric and sensor development for (i) seaweed characterisation and (ii) to facilitate the transfer of my PhD findings to the Irish mushroom industry. My current research is funded by the EC FP7 Marie Curie International Outgoing Fellowship programme. My outgoing host was the Food Quality Laboratory, U.S. Department of Agriculture, Beltsville Agricultural Research Center, MD, USA. I also assisted in the supervision of PhD and MSc students. I was previously a lecturer in universities in Peru and Chile.

**Recent Publications**

Achata, E.; Esquerre, C.; O'Donnell, C.; Gowen, A. A study on the application of near infrared hyperspectral chemical imaging for monitoring moisture content and water activity in low moisture systems. Molecules 2015, 20, 2611-2621.


Colm Everard, BE, PhD, Uni Cert Stats

Project Title: Spectral Imaging for Contaminant Detection on Fresh Food Produce

Project Leaders: Prof Shane Ward and Dr Moon Kim

Abstract
The objective of my current research is to develop and validate on-line, non-destructive hyperspectral imaging technologies to rapidly assess safety and quality of fresh foods. This will reduce food safety risks in pre-harvest and post-harvest production. Multitask inline hyperspectral imaging, macro-scale laser-induced fluorescence imaging, Raman hyperspectral imaging, and image-based portable handheld inspection devices will be developed for detection of food safety issues.

Background, Skills & Qualifications
I obtained a BE and PhD in Biosystems Engineering at UCD. I also obtained a University Certificate in Statistics at UCD. I joined Teagasc (Moorepark Food Research Centre) as a Research Officer in 2005 working on the development to cheese syneresis control technologies for improved product consistency. In 2008, I was awarded an IRCSET fellowship through their EMPOWER scheme, hosted by UCD. Subsequently, I was employed as a post-doctoral researcher on the Charles Parsons Energy Research Award at UCD. During this period I was awarded a 5 month SFI - Short Term Travel Fund to develop mathematical models to predict heating in Irish indigenous biomass crop piles and my host was the Reactive Substances and Systems Division at BAM Federal Institute for Materials Research and Testing, Berlin, Germany. I am currently an EC FP7 Marie Curie International Outgoing Fellow and my outgoing host is the Environmental Microbial and Food Safety Laboratory, US Department of Agriculture, Agricultural Research Service, MD, USA.

Recent Peer-reviewed Publications

Abstract

Biochar is charcoal which has been created under anaerobic conditions through the pyrolysis of biomass. Applying biochar to soils results in long term carbon sequestration, improvement of soil properties and biomass waste management while syngas produced in the process may be used as an energy source. The current resources for biochar production Ireland include excess agricultural residues of straw, farmyard manure (FYM), poultry litter and spent mushroom compost (SMC). The produced biochar may be added to agricultural animal feed (giving the animals a number of health and digestive benefits) while it ultimately ends up in collected manure. While residing in the manure the biochar becomes “charged” with nutrients before being applied to the land where it provides many benefits to the soil, reduces leaching of nutrients and improves crop growth. While food production leads to GHG emissions, good soil management, such as the application of biochar, can lead to long term storage of carbon in soil while also improving soil structure and fertility.

Background, Qualifications and Skills

In 2008 I graduated from UCD with a degree in Biosystems Engineering and subsequently took up the opportunity of doing a PhD as part of the Charles Parsons Energy grant funded by SFI. My research area was the use of biological media to mitigate carbon from the flue gases of point source emitters such as fossil fuelled power plants. This process leads to the production of large amounts of biomass while reducing emissions from the point source. Biomass may be used for a number of useful applications, with the selected application determining the fate of captured carbon (i.e. released or sequestered). During my research I focused on the use of microalgae for this purpose and the title of my thesis was the “Potential for Production of Microalgal Biomass in CO₂ Enhanced Gas Streams with Specific Focus on the Bio-Fixation of Carbon by Microalgae” under the supervision of Dr. Kevin McDonnell. After completion of my PhD in 2013 I took up the opportunity of becoming a postdoctoral fellow also in the Charles Parsons Energy group.

Recent Publications


Niall O’Brien, BE, M.EngSc., PhD

Project Title: Integrating engineered nanomaterial (ENM) kinetics with environmental exposure modelling

Project Leader: Dr. Enda Cummins

Abstract
The “nanoADJUST” project aims to develop expertise in the application of techniques and tools used to characterise and analyse the behaviour of metallic engineered nanomaterials (ENMs) in natural aquatic media and integrate this expertise with environmental exposure modelling and risk management data requirements and processes. Data handling throughout the risk assessment (RA) process will be analysed and a statistical framework for the acquisition and management of nano-relevant data at all stages will be developed. Partitioning experiments in natural aquatic environmental matrices will be undertaken, generating data for use in exposure modelling and RA. Fit-for-purpose analytical methodology shall be developed for quantification of nanoparticle related elemental concentrations in model experiments and natural aquatic environmental matrices. Behavioural indicators or descriptors (i.e. partitioning likelihood distributions) shall also be developed for use in metallic ENM experimental analysis, exposure monitoring and risk assessment, and identification of organisms at risk of metallic ENM toxicity.

Background, Skills & Qualifications
My PhD thesis, concerning the development of development of a risk assessment methodology for evaluating ecological dispersion and human health risks from nanoparticles through environmental pathways, was completed in 2010 under the supervision of Dr. Enda Cummins. This involved developing techniques in environmental modelling, environmental risk assessment and bench mark dose modelling. I obtained a Masters in Engineering Science in the area of renewable fuel production in 2006 and a BE in Biosystems Engineering in 2004, both from UCD.

I am currently funded as an EU FP7 Marie Curie International Outgoing Fellow at the Centre for the Environmental Implications of Nanotechnology (CEINT), based in the Civil and Environmental Engineering Department, Duke University, NC, USA.

Recent Publications


Cecilia Riccioli, BA, PhD

Project Title: Hyperspectral imaging technology for the quality inspection of fish products (SPECTRAFISH)

Project Leader: Dr. Da-Wen Sun

Abstract
In recent years, hyperspectral imaging (HSI) has gained a wide recognition as a non-destructive and fast quality and safety analysis and assessment method for a wide range of food products.

The SPECTRAFISH project aims to bridge the lack of rapid and objective methods of non-invasively inspecting based on quality and safety attributes of finfish products. The system will integrate two conventional optical sensing technologies of computer vision and near infrared spectroscopy into unique imaging sensors, a hyperspectral imaging system that can provide not only spatial but also spectral information for each pixel in an image.

The development of a hyperspectral imaging device for the automatic, rapid, objective and non-invasive measurement of quality and safety attributes of finfish fillets will be carried out throughout the project.

Background, Skills & Qualifications
I have been working for more than seven years in the research field of the HIS related to the near infrared technology for quality and safety control in agro-food products. In particular, I’m interested in the study of the relationship between the spectroscopic properties of food and physical and chemical properties. I have large experience in the use of chemometrics techniques to create prediction models able to detect and quantify different safety and quality parameters in food.

I received my PhD from the Department of Animal Production at Universidad de Córdoba (Spain) in 2011. I obtained a BA in Science and Technology of Food from the University of Florence (Universita’ degli studi di Firenze, Italy) in 2005.

Recent publications


Eilín Walsh, BSc (Hons) MSc (Agr), PhD

**Project Title:** Sustainable Energy and Green Technologies

**Project Leader:** Dr. Kevin McDonnell

**Introduction**

The MSc in Sustainable Energy and Green Technologies programme offered by the School of Biosystems Engineering is underpinned by the best European practice by incorporating compatible EU policy drivers such as the Strategic Energy Technology Plan (SET Plan) for energy research, current R&D in green technologies through ongoing research initiatives under the Charles Parsons Energy Research programme, and collaboration with internationally acknowledged experts in the subject domains. One of the requirements of the Sustainable Energy and Green Technologies programme is that students conduct a research project focussed on a topic within the field which is presented as a minor dissertation. After the dissertations have been submitted I then assess each project for relevancy and novelty before using the students’ dissertation as a base to prepare an article for publication. Depending on the topic, the articles are prepared either for peer review or for a popular press publication. In this way, I have a significant responsibility for raising the profile of both the School of Biosystems Engineering and the Sustainable Energy and Green Technologies programme both nationally and internationally. I also work with the Charles Parsons Energy Research team on their activities in both peer review and popular press publications to highlight the research activities and outputs of this project.

**Background, Qualifications and Skills**

Joining the School of Biosystems Engineering was a natural choice for me. In 2005, having completed a Bachelor of Science degree in Environmental Biology in UCD, I joined the School of Biosystems Engineering to undertake a Masters of Science (Agriculture) before completing a PhD under the supervision of Dr. Kevin McDonnell. My PhD focussed on sustainable agriculture, specifically the use of industry-derived organic materials as an alternative to synthetic fertilisers to enhance soil fertility and productivity. It was during my PhD that my aptitude for technical and scientific writing became apparent and I am highly regarded amongst my peers for my writing, proofreading, and editing skills. Upon completion of my PhD research I followed an obvious progression to my current position.

**Recent Publications**


Appendix 3

UCD School of Biosystems Engineering: Postgraduates 2014/15 as photographed by Sean Kennedy
Appendix 4

UCD School of Biosystems Engineering : Staff and Post Docs
2014/15 as photographed by Sean Kennedy