New technologies to monitor and improve silage quality from field to feed-out

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‘Man masters nature not by force but by understanding.

This is why science has succeeded where magic failed:

because it has looked for no spell to cast over nature’

Jacob Bronowski
Author of the Ascent of Man
Three distinct phases

Growing

Feeding

Harvesting/Ensiling

Quality of Silage

LOSSES
Challenge

To integrate existing knowledge/measurements with new technologies to provide ‘on-farm decision making tools’ to enable ‘instantaneous’ information to the forage manager.
Growing

- Nutrient availability/requirement
- Quality
  - Fermentation
  - Sugar/Buffering
  - Nutritional
    - DM/Protein/Digestibility/Starch
  - Microbiological
    - Fungal/ Bacteria Undesirable/Desirable
Harvesting/Ensiling

• Quantity vs Quality
  – Yield
  – Milk/Meat per Ha/Ac

• Microbiology
  – Aerobic Stability/Fermentability Index

• Cutting Height

• Wilting - %DM

• Density
Feed-Out

• Quality vs Change in Quality
  – Nutrient
  – Microbiological
  – Toxins
  – Temperature
LOSSES
Visible and Invisible

Sugar Loss and Impact on Digestibility between Mowing and harvesting
A history of forage monitoring

• Use of precision tools in the arable industry is now common place (variable rate applications) yet forage management remains relatively low-tech (Schellberg et al., 2008)
• Pasture management software is available but collection of biomass data is time-consuming (walking fields – rising plate meter or capacitance probe)
• Optimising forage involves accurate timing of sowing, input application and cutting
• Sward management becomes increasing complex where species mixtures are used
• There is a need for real-time decision support tools to aid farmers in monitoring sward development.

Maturity?
Chemical composition?
Species composition – weeds?
Fertiliser requirement?
Monitoring soil status

- Monitoring soil fertility and nutrient status is key for short-term crop growth and long-term sustainability.
- Real-time data could lead to increased application precision of fertilisers, lime and other inputs.
- E.g. Shaw *et al.* (2016) developed an in situ nitrogen sensor network that could be buried in the soil.
- Further development of sensors to also allow determination of other macro and micro nutrients would be desirable.

Shaw *et al.* (2016)
Monitoring via satellite

• Remote sensing via satellite enables data to be transmitted direct to the farm office or a smartphone – less labour needed to make manual observations

• A number of satellites to choose from – wavelength bands/frequency of coverage and pixel resolution differ

• **Cloud coverage** and **infrequent passes** still hinder application

• Sentinels 1 and 2 (launched 2015 and 2016) offer improvements over previous older satellites (Landsat/MODIS/SPOT)
Obtaining data Using spectra

• Absorbance/reflectance of electromagnetic wavelengths can be measured using **multi-spectral sensors** attached to satellites.

• Data can be used to obtain **vegetation indices** which are correlated with biomass (and other characteristics…).

• **NDVI** is amongst the most commonly utilised for forage applications.

• **High resolution** satellites allow for more accurate and advanced calculation of indices.

Perez-sanz *et al.*, 2015
PASQUAL STUDY
Innovate UK funded study at University of Reading (2016-2018)
Integrating satellite data and pasture growth models to overcome issues with infrequent passes/cloud cover
Starting with biomass prediction – aims to also predict some quality parameters (protein/fibre?)

Sentinel 2a satellite data
Pasture growth model
Leaf Area Index
Model calibration
Prediction of Pasture Yield and Quality

Daily weather Data + management info.

Suvarna Punalekar, Anne Verhoef, Tristan Quaife, Louise Bermingham, David Humphries, Chris Reynolds
Available Biomass (Kg/ Ha)

- < 500
- 500.1 - 1,000
- 1,000.1 - 1,500
- 1,500.1 - 2,000
- 2,000.1 - 2,500
- 2,500.1 - 3,000
- 3,000.1 - 3,500
- 3,500.1 - 4,000
- 4,000.1 - 4,500
- 4,500.1 - 5,000

PASQUAL study

Punalekar et al., Unpublished
PASQUAL: Multispecies sward
Enabling biomass estimation for alternative forages that are unsuited to conventional methods.

- Perennial Ryegrass (control)
- 6 species mixed sward
- 12 species mixed sward
- 17 species mixed sward

Punalekar et al., Unpublished
In-FIELD SENSING

Portable Near Infra-Red Spectrometry

• Several devices available for use analysing silages on farm.
• Near infra-red can predict chemical composition data
• Robust NIR machines have been successfully mounted to forage harvesters for in line assessments of crop dry matter (e.g. Haldrup, Germany).

Thermal imaging

• precision management of drought stress?
• Utilised to identify ears of grain for yield evaluation in arable crops (Rothamsted research, Virlet et al., 2016)
• Grassland canopy temperatures can vary depending on species (e.g. C3 or C4 grasses – Shimoda et al., 2006)
Harvesting and Ensiling

Pre- and post cutting quality assessments

- NIRS
- UAV (Drone) imaging
- Chlorophyll - As a marker of protein content
- Picture phone app to identify phenophase and link to digestibility
- Field based ELISA for microbial biomass
On Farm NIRS
Quote

‘The greatest enemy of knowledge is not ignorance; it is the illusion of knowledge’

Stephen Hawkin
Harvesting and Ensiling
Monitoring %DM

Thermal imaging Drone

Thermal imaging
- Relationship between water content and heat
- It takes 1 kilocalorie to heat 1 kg of water by 1°C
- As crops wilt DO they become hotter?

Effect of wilting on change in %DM, WSC and % Digestibility between Mowing and harvesting
Weigh Cells on trailer communicating to forage harvester

- Patented blue tooth technology between trailer weigh cells and variable flow rate applicator
- Adjustable additive application rate
- More forage hits the trailer!
Silo Density

Fresh Matter density a NIRS calibration with an $r^2 = 0.63$
Volatiles and e-nose could be developed to measure wilting, fermentation and nutritional quality and palatability.
Spoiled silage can be visible or invisible

- Invisible spoiled areas
- Visible moulded areas
- Well conserved silage
Contribute of mixing well conserved silage with aerobic deteriorated upper layer on chemical and microbial quality of maize silage

<table>
<thead>
<tr>
<th>Chemical quality</th>
<th>Incidence</th>
<th>pH</th>
<th>Starch (g/kg DM)</th>
<th>NDF (g/kg DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td></td>
<td>6.84</td>
<td>28.0</td>
<td>51.2</td>
</tr>
<tr>
<td></td>
<td>4.0%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>96%</td>
<td>3.64</td>
<td>32.9</td>
<td>38.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Microbial quality (log cfu/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yeast</td>
</tr>
<tr>
<td>6.33</td>
</tr>
<tr>
<td>2.93</td>
</tr>
</tbody>
</table>

Mean data of commercial farms in northern Italy adapted from Borreani and Tabacco (2010) and Tabacco et al. (2011)
Resulting mixed silage for TMR and contribution of the upper layer to chemical and microbial quality of silage

<table>
<thead>
<tr>
<th></th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>100%</td>
</tr>
<tr>
<td>Starch (% DM)</td>
<td>80%</td>
</tr>
<tr>
<td>NDF (% DM)</td>
<td>60%</td>
</tr>
<tr>
<td>Yeast (log cfu/g)</td>
<td>40%</td>
</tr>
<tr>
<td>Mould (log cfu/g)</td>
<td>20%</td>
</tr>
<tr>
<td>Anaer. spore</td>
<td>0%</td>
</tr>
</tbody>
</table>

Mixed silage for TMR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (log cfu/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>3.66</td>
</tr>
<tr>
<td>Starch (% DM)</td>
<td>32.7</td>
</tr>
<tr>
<td>NDF (% DM)</td>
<td>39.1</td>
</tr>
<tr>
<td>Yeast (log cfu/g)</td>
<td>4.94</td>
</tr>
<tr>
<td>Mould (log cfu/g)</td>
<td>6.60</td>
</tr>
<tr>
<td>Anaerobic spore (log cfu/g)</td>
<td>3.70</td>
</tr>
</tbody>
</table>
Microbiological quality of corn silage at different levels of spoilage

<table>
<thead>
<tr>
<th></th>
<th>Good silage</th>
<th>Deteriorated silage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Warm</td>
</tr>
<tr>
<td>Visible mould</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>20.2</td>
<td>47.5</td>
</tr>
<tr>
<td>dT (°C)</td>
<td>-2.5</td>
<td>24.1</td>
</tr>
<tr>
<td>DM losses (%)</td>
<td>5.0</td>
<td>13.1</td>
</tr>
<tr>
<td>pH</td>
<td>3.51</td>
<td>4.95</td>
</tr>
<tr>
<td>Yeast (log cfu/g)</td>
<td>3.05</td>
<td>7.45</td>
</tr>
<tr>
<td>Mould (log cfu/g)</td>
<td>2.09</td>
<td>4.34</td>
</tr>
</tbody>
</table>

(Tabacco et al., 2011)
Depressed quality in deteriorated maize silage

<table>
<thead>
<tr>
<th></th>
<th>Good silage</th>
<th>Deteriorated silage</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Warm</td>
<td>Mouldy</td>
</tr>
<tr>
<td>Ash, % DM</td>
<td>3.17</td>
<td>3.44</td>
<td>4.75</td>
</tr>
<tr>
<td>NDF, % DM</td>
<td>41.0</td>
<td>45.7</td>
<td>52.6</td>
</tr>
<tr>
<td>ADF, % DM</td>
<td>21.1</td>
<td>23.7</td>
<td>32.4</td>
</tr>
<tr>
<td>Starch, % DM</td>
<td>36.6</td>
<td>35.5</td>
<td>29.6</td>
</tr>
</tbody>
</table>

(Tabacco et al., 2011)
New tools to improve monitoring of silage quality at feed-out for precision agriculture

<table>
<thead>
<tr>
<th>Characteristics to be monitored</th>
<th>Tools</th>
<th>Application for precision feeding systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Temperature sensors</td>
<td>New generation balers</td>
</tr>
<tr>
<td>pH</td>
<td>Infrared thermography</td>
<td>TMR mixer wagon</td>
</tr>
<tr>
<td>Yeast and mould</td>
<td>Wireless sensor nodes</td>
<td>Feeding robots fully automated</td>
</tr>
<tr>
<td>Sporeformers</td>
<td>Portable pHmeter</td>
<td></td>
</tr>
<tr>
<td>Pathogens</td>
<td>Portable NIRS</td>
<td></td>
</tr>
<tr>
<td>Mycotoxins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM losses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fermentative products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutritive quality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Probe or spike thermometers

**Strengths**
- No effect of environmental temperature
- Low cost
- Measurement at different depths in the silo

**Weaknesses**
- Time consuming
- Difficult to safely measure big stacks
Thermal infrared cameras

**Strengths**

- Fast
- Whole image in one shot
- Safely measurement of big silos

**Weaknesses**

- Negative interaction with sun exposure (hour of the day!)
- Face measurement only (max 1 cm depth)
- Needed experience to correctly interpret results
Infrared thermography

Sunny  Shaded
Temperature logger

**Strengths**

- Buried in the mass at ensiling
- Follows evolution of temperature during storage and feedout phase
- Possibility of recording long period of data (up to 1 year)

**Weaknesses**

- Experimental purpose only
- Local measurement only
- Difficult to retrieve in the silage
Wireless sensor nodes (Green et al., 2009)

**Strengths**
- Buried in the mass at ensiling
- Transmission of measured data through the network

**Weaknesses**
- High cost (prototype)
- Experimental purpose only
- Local measurement only
Different *in situ* oxygen sensors for monitoring silage (Shanet al., 2016)

Dimensions of oxygen (O$_2$) sensors, (a) Dräger chip measurement system (DCMS); (b) the Clark oxygen electrodes (COE); (c) galvanic oxygen cell (GOC)
Fully automated feeding and feed mixing robots

Robotic systems opened new perspectives and requirements with regard to technologies to monitor and improve silage quality and aerobic stability for implementation and successful application at farm level.
Technology to improve Quality AND reduce variability

Width - 17.9 m, Height 2.6 m at the shoulders and 3.9 m in the centre

DM = 18.5; ME = 9.76
CP = 9.26; pH = 7.94

DM = 22.4; ME = 10.74
CP = 10.83; pH = 3.73

DM = 24.4; ME = 9.76
CP = 12.58; pH = 5.60

DM = 26.4; ME = 10.37
CP = 12.8; pH = 4.48

DM = 20.5; ME = 10.09
CP = 10.12; pH = 5.68
Implementing new technologies

• Significant advancements continue to be made in forage technology however the key to success is to integrate them into systems intuitively

• Options for integration include
  – Attaching sensors to vehicles e.g. ATV-mounted ultrasound, N-sensor technology for tractors (www.yara.co.uk)
  – Collecting images using UAV
  – Developing remote sensing software for direct data transfer from satellites to the farm office
  – Increasing the integration between machinery using smartphone and wireless technologies

• Work towards fully robotic systems that require minimal human input for management decisions
Thank you for your attention

Any Questions?