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

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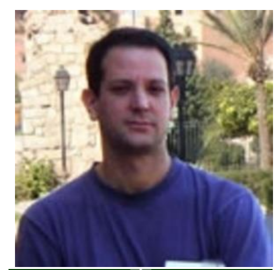
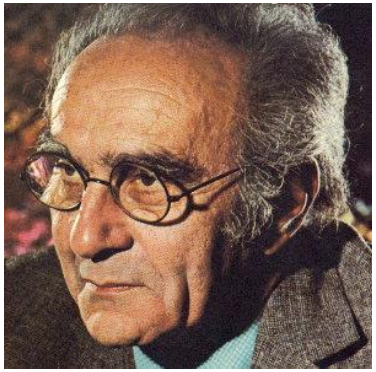


‘Man masters nature not by force but by understanding.

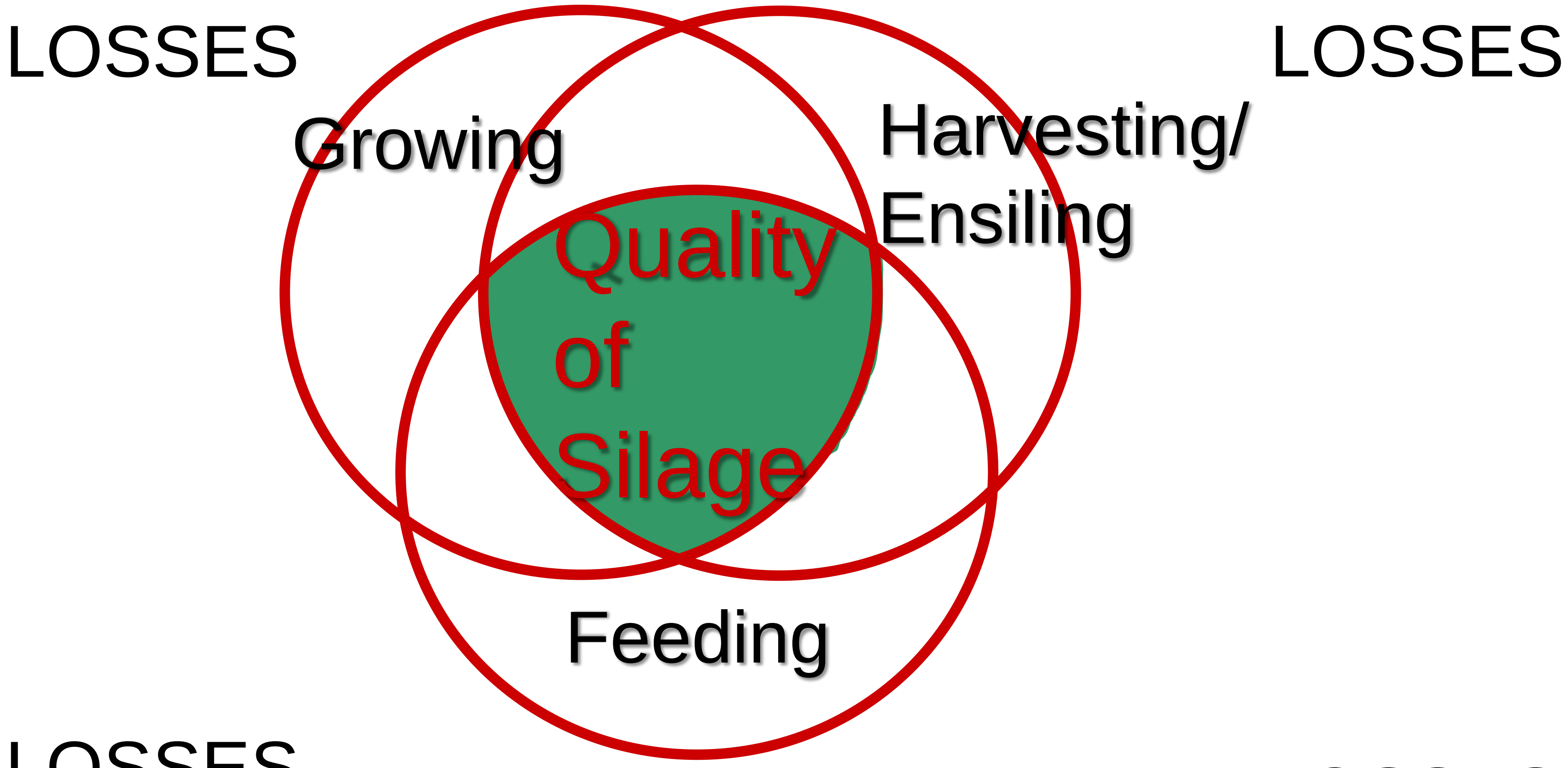
This is why science has succeeded where magic failed:

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



Jacob Bronowski
Author of the Ascent of Man

Three distinct phases



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

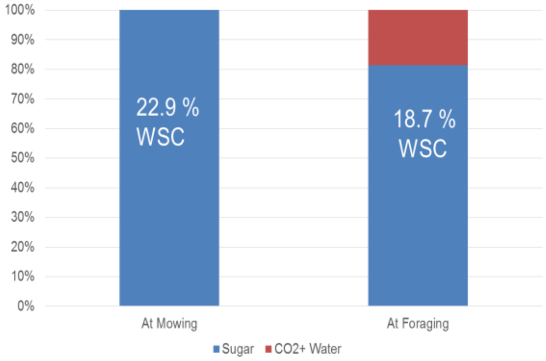
- Quantity vs Quality
  - Yield
  - Milk/Meat per Ha/Ac
- Microbiology
  - Aerobic Stability/Fermentability Index
- Cutting Height
- Wilting - %DM
- Density

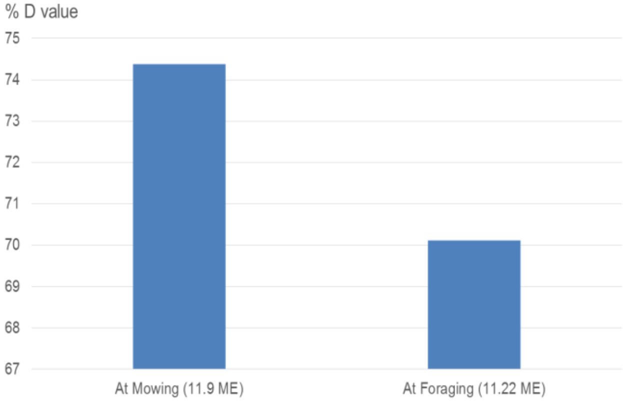
Feed-Out

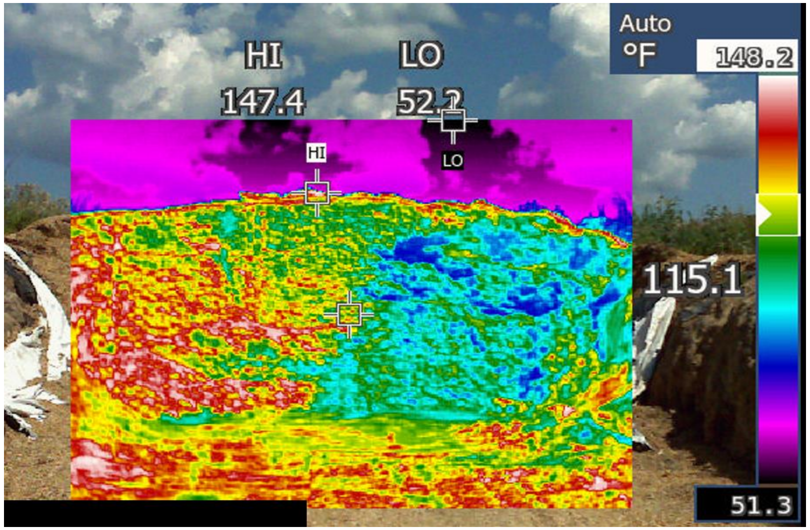
- Quality vs Change in Quality
  - Nutrient
  - Microbiological
  - Toxins
  - Temperature

LOSSES
Visible and Invisible

Sugar Loss and Impact on Digestibility between Mowing and harvesting







GROWING

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.

Monitoring soil status

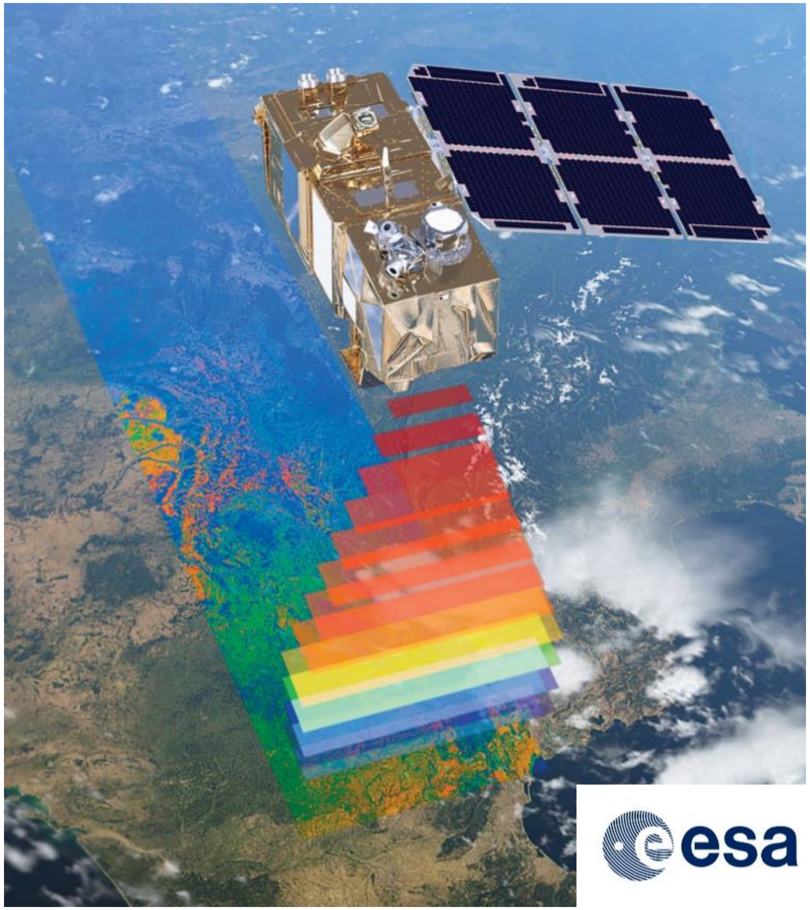
- Monitoring soil fertility and nutrient status is key for short-term crop growth and long-term sustainability
- Real-time data could lead to increased application precision of fertilisers, lime and other inputs.

- 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)

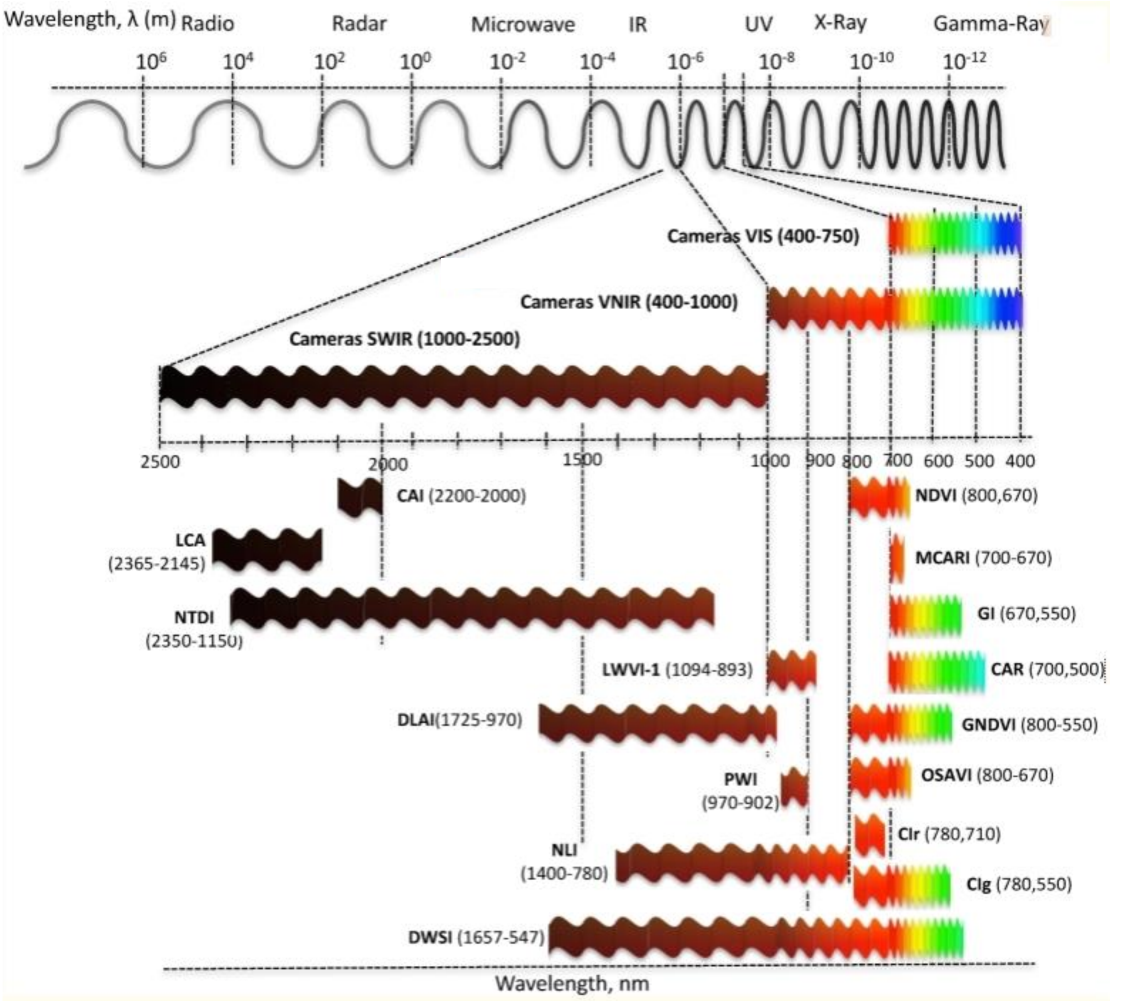
Monitoring via satellite

- 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 hinders 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



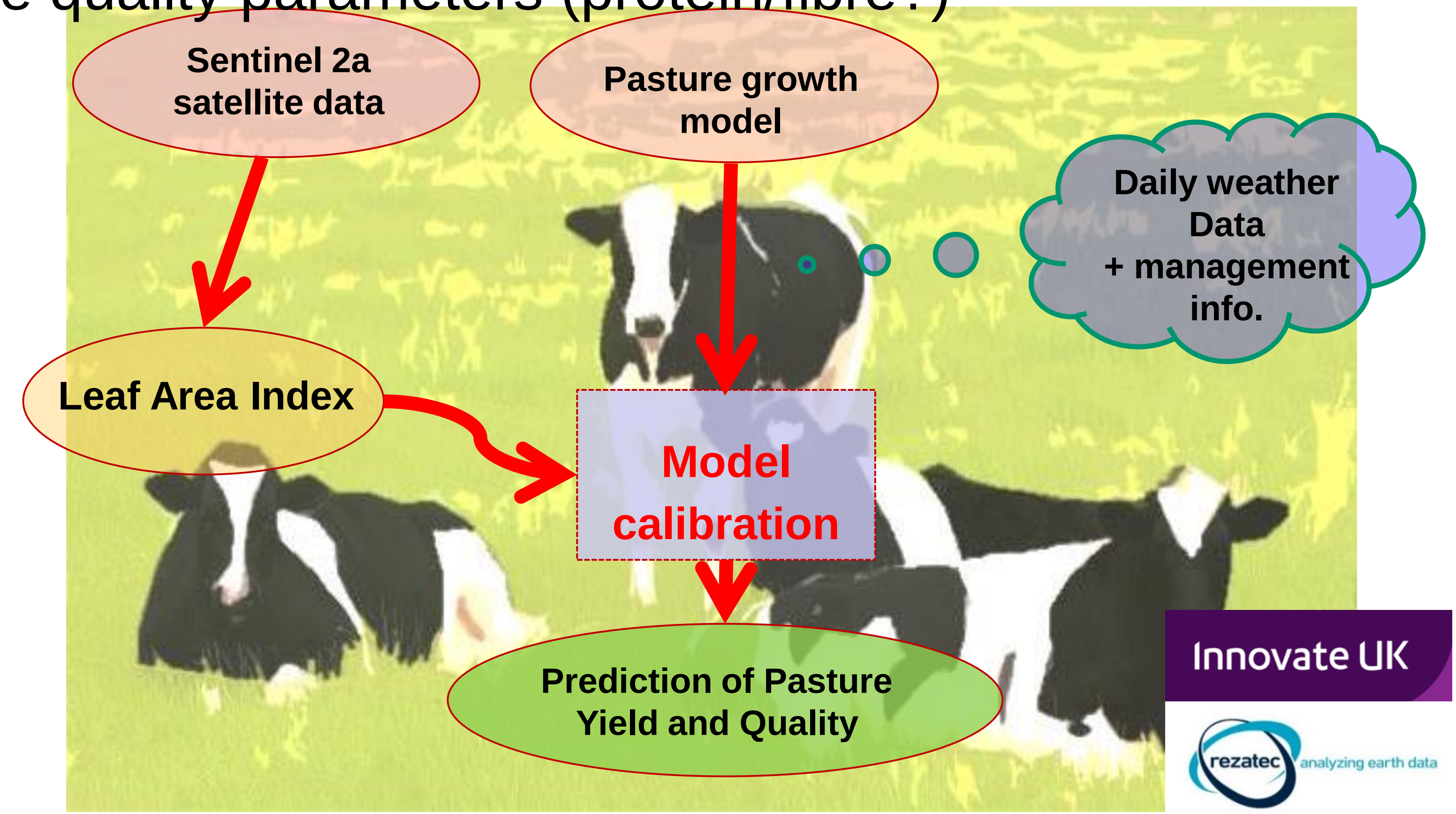
Perez-sanz *et al.*, 2015

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?)



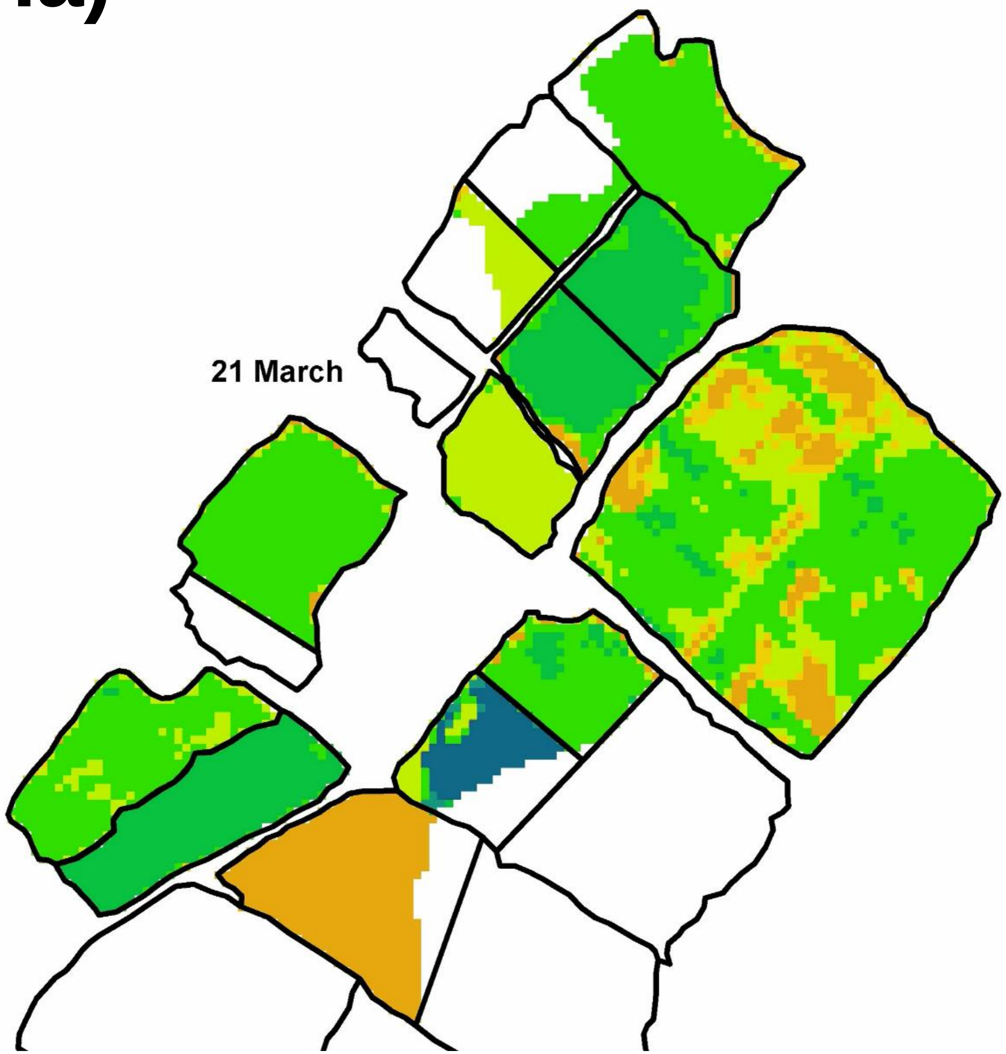
Suvarna Punalekar, Anne Verhoef, Tristan Quaife, Louise Bermingham, David Humphries, Chris Reynolds

PASQUAL study

Available Biomass (Kg/ Ha)

Punalekar *et al.*, Unpublished

- < 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



rezatec analyzing earth data

Innovate UK

PASQUAL:
Multispecies sward

Enabling biomass estimation for alternative forages that are unsuited to conventional methods.

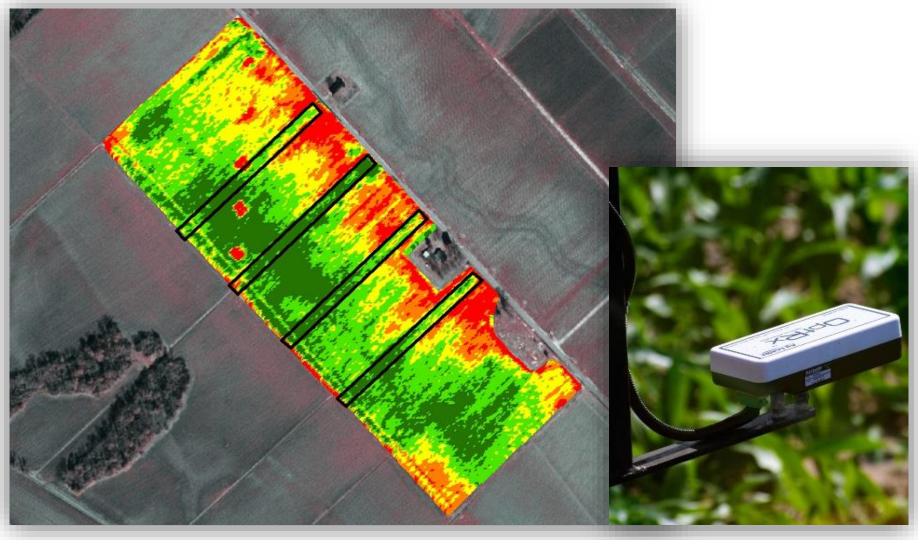
- Perennial Ryegrass (control)
- 6 species mixed sward
- 12 species mixed sward
- 17 species mixed sward

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

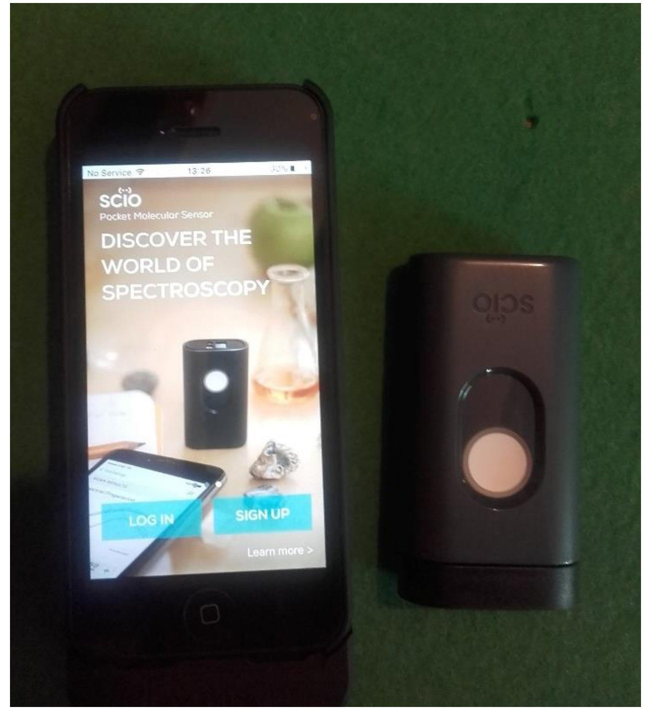
- precision management of drought stress?
- Utilised to identify ears of grain for yield evaluation in arable crops (Rothamsted research, Virlet *et al.*, 2016)
- Grassland canopy temperatures can vary depending on species (e.g. C3 or C4 grasses – Shimoda *et al.*, 2006)

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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Quote

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

Stephen Hawkin

Harvesting and Ensiling

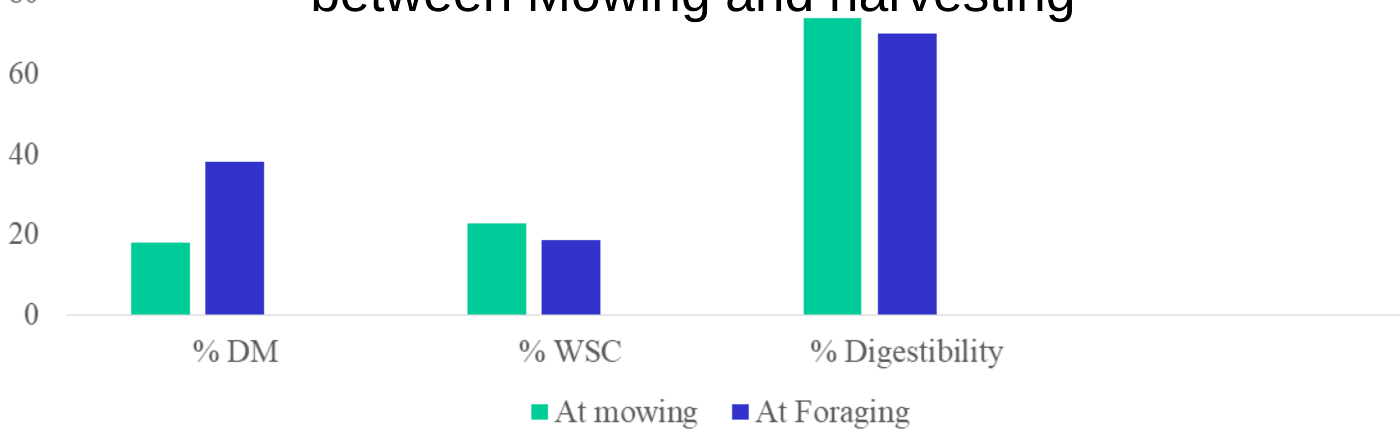
Monitoring %DM

Thermal imaging Drone

Thermal imaging

- Relationship between water content and heat
- It takes 1 kilocalorie to heat 1 kg of water by 1^{o}C
- As crops wilt DO they become hotter?

Effect of wilting on change in %DM, WSC and % Digestibility between Mowing and harvesting



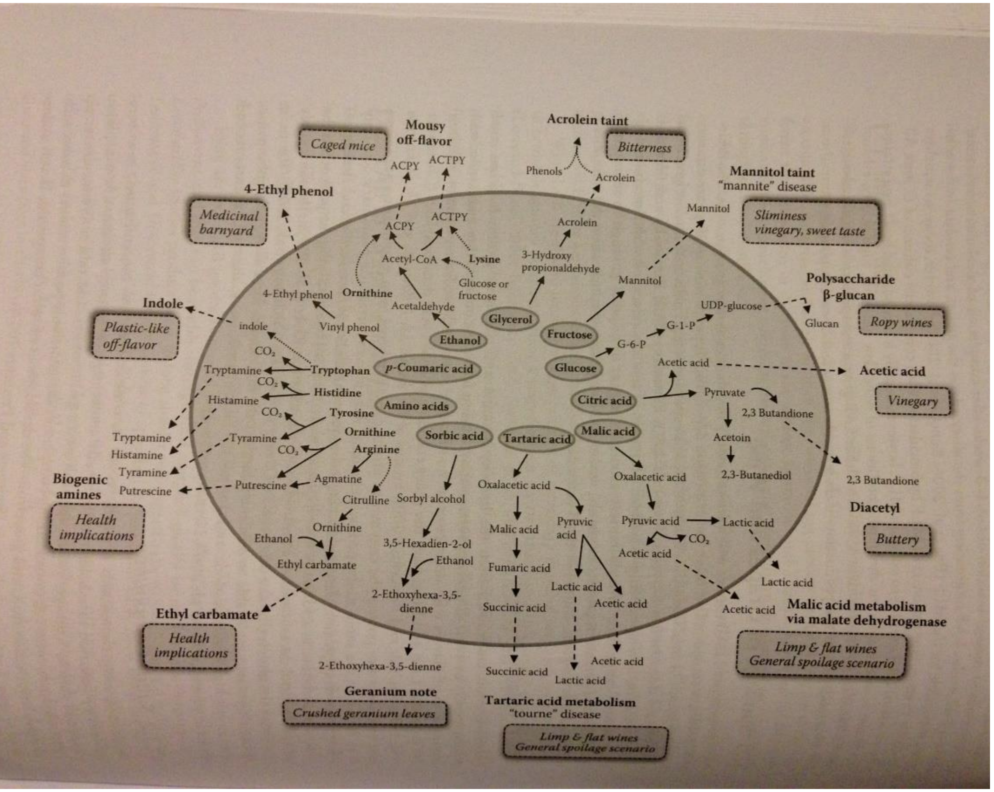
Weigh Cells on trailer communicating to forage harvester

- 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

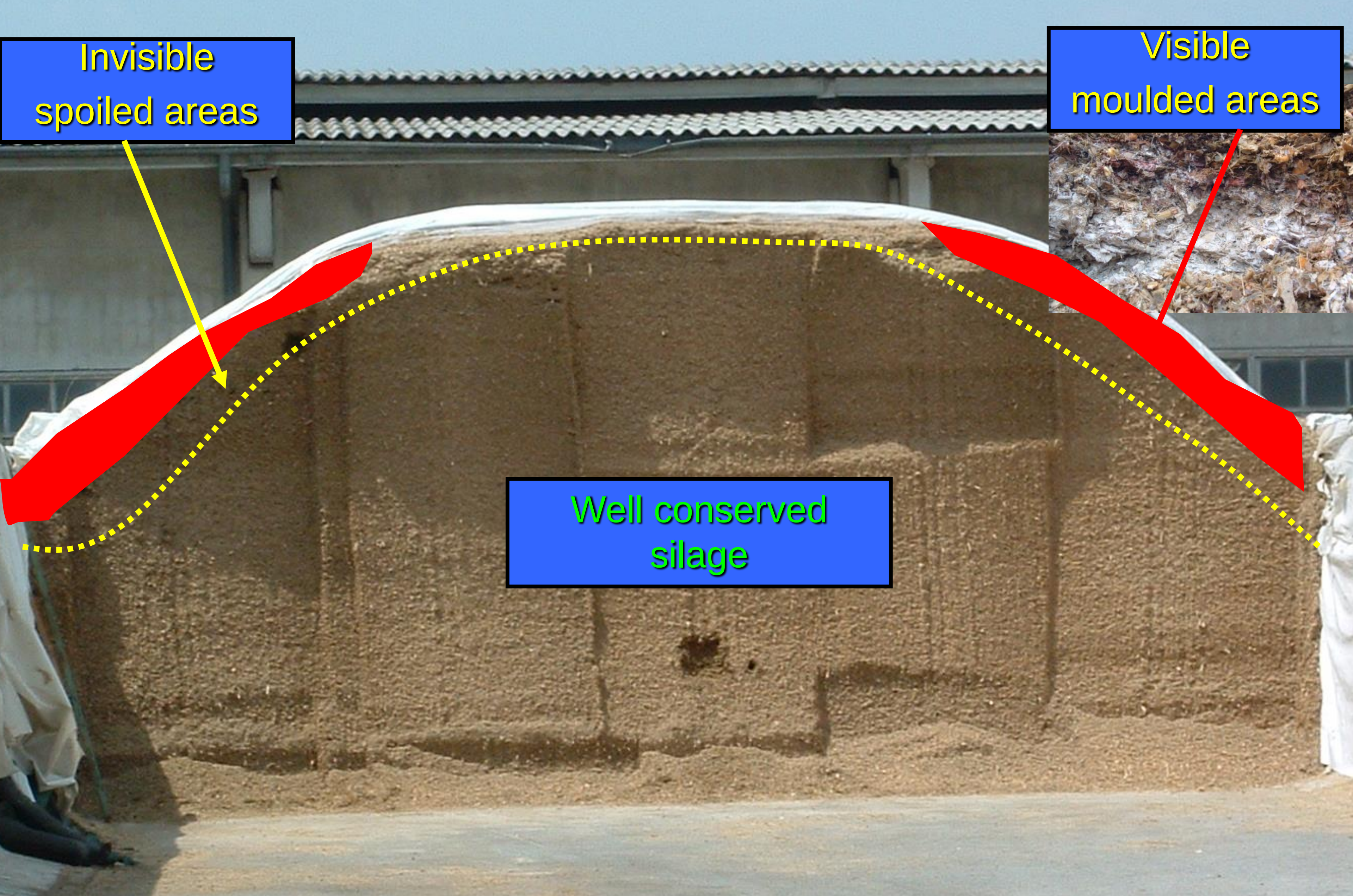


2-Octan-1-ol	Wheat	*Asp.flavus, Asp.ochraceus, Asp.oryzae, Asp.parasiticus, Asp.nidulans, Pen.chrysogenum, Pen.raistricki, Pen.viridicatum Alt.* Spp., *Cephalosporium* spp, *Fus.* spp	Kaminski et al. (1972, 1974)
1,5-Octadien-3-ol	Whole wheat bread	*Pen.roquefortii*	Harris et al. (1986)
Hexanol	Wheat/maize	*Asp.flavus, Asp.parasiticus, Pen.chrysogenum, Alt.* spp	Wasowicz (1988)
Octanol	Whole wheat bread	*Asp.flavus, Asp.niger*	Harris et al. (1986)
Carbonyls			
Acetaldehyde	Wheat/maize	*Asp.flavus, Asp.parasiticus, Pen.chrysogenum, Alt.* spp	Wasowicz (1988)
2-Pentane	Wheat	*E.amstelodami*	Borjessön et al. (1989)
3-Octanone	Wheat	*Asp.flavus, Asp.ochraceus, Asp.oryzae, Asp.parasiticus, Asp.nidulans, Pen.chrysogenum Pen.citrinum, Pen.funiculum Pen.raistricki, Pen.viridicatum, Alt.* spp., *Cephalosporium* spp, *Fus.* spp	Kaminski et al. (1972, 1974)
	Whole wheat bread	*Pen.roquefortii, Asp.flavus, Asp.niger*	Wasowicz (1988)
	Wheat	*E.repens, Pen.cyclopium*	Tuma et al. (1989)
Nonanal	Whole wheat bread	*Asp.flavus, Asp.niger*	Harris et al. (1986)
2-Methylo-acetophenone	Barley	*Pen.coprophilum*	Wilkins and Scholl (1989)
Hydrocarbons			
Dimethyl benzene	Whole wheat bread	*Asp.flavus, Asp.niger*	Harris et al. (1986)
Trimethyl hexane	Whole wheat bread	*Pen.roquefortii*	Harris et al. (1986)
2, 4-Dimethyl hexane	Wheat	*Fus.culmorum*	Borjessön et al. (1989)
Styrene	Barley	*Pen.aurantiogriseum, Pen.verrucosum, Pen.viridicatum, Pen.coprophilum*	Wilkins and Scholl (1989)
Naphthalene	Whole wheat	*Asp.niger*	Harris et al. (1986)
Miscellaneous			
Ethyl acetate	Wheat	*Fus.culmorum*	Borjessön et al. (1989)
2-Methyl-furan	Wheat	*E.amstelodami, Asp.flavus, Pen.cyclopium*	Borjessön et al. (1989)
2-(1-Pentyl)-furan	Barley	*Pen.aurantiogriseum, Pen.verrucosum, Pen.viridicatum, Pen.coprophilum*	Wilkins and Scholl (1989)
2-(2-Furyl)-pentanal	Barley	*Pen.aurantiogriseum, Pen.verrucosum, Pen.viridicatum, Pen.coprophilum*	Wilkins and Scholl (1989)
2-Ethyl-5-methyl-phenol	Barley	*Pen.aurantiogriseum, Pen.verrucosum, Pen.viridicatum, Pen.coprophilum*	Wilkins and Scholl (1989)
3-Methyl-anisole	Barley	*Pen.aurantiogriseum, Pen.coprophilum*	Wilkins and Scholl (1989)
Monoterpenes	Wheat	*Fus.culmorum*	Borjessön et al. (1989)
2-Methyl-isoborneol	Whole wheat bread	*Pen.roquefortii*	Harris et al. (1986)
Damascenone	Whole wheat bread	*Pen.roquefortii*	Harris et al. (1986)

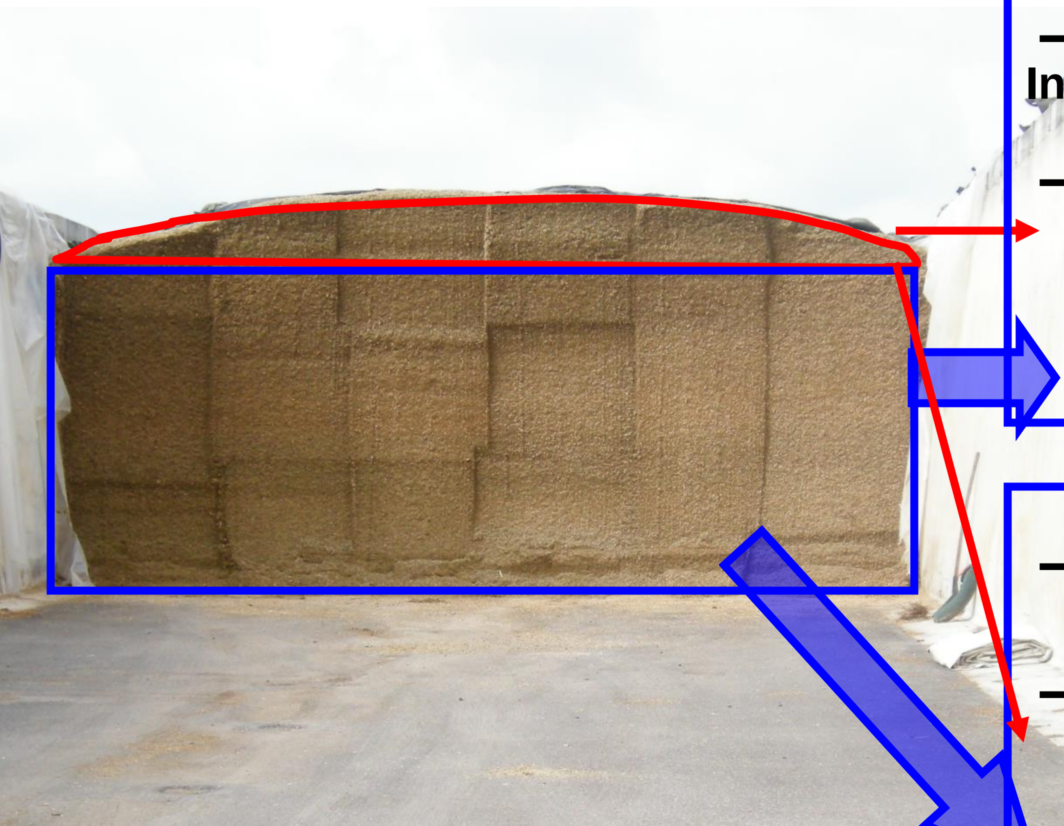
Volatiles and e-nose could be developed to measure wilting, fermentation and nutritional quality and palatability

Eg Masoero *et al* 2007

Spoiled silage can be visible or invisible



Contribute of mixing well conserved silage with aerobic deteriorated upper layer on chemical and microbial quality of maize silage



Chemical quality

Incidence DM	pH	Starch	NDF
		(g/kg DM)	
4.0%	6.84	28.0	51.2
96%	3.64	32.9	38.6

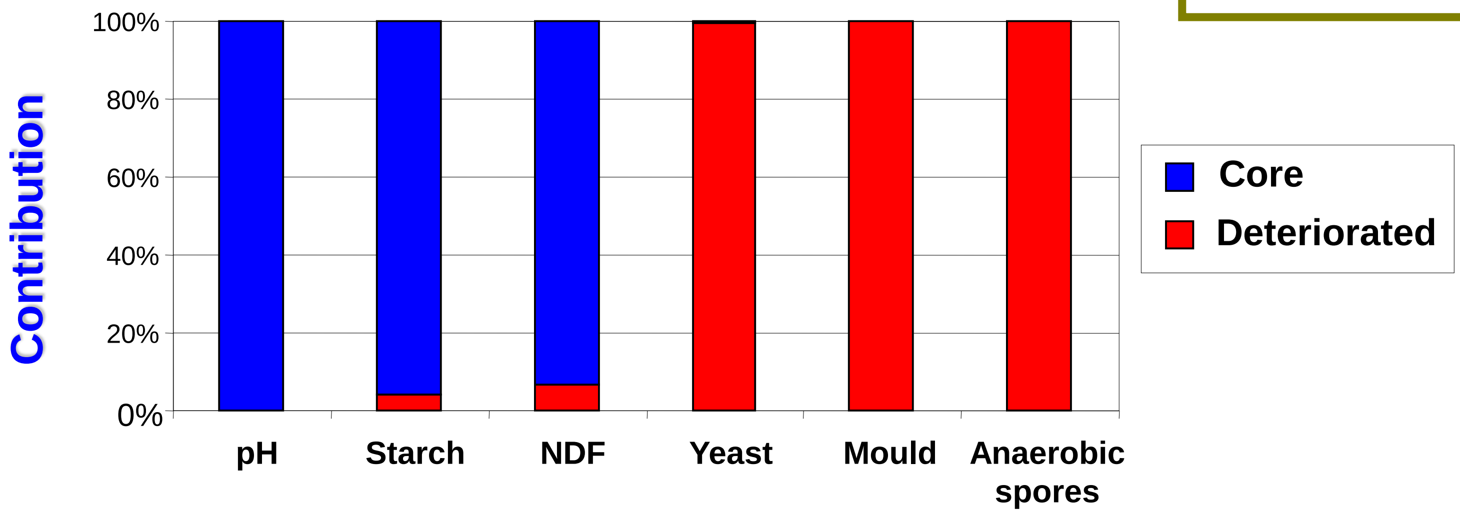
Microbial quality (log cfu/g)

Yeast	Mould	Anaerobic spore
6.33	8.01	5.10
2.93	1.76	1.40

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

Mixed silage for TMR	
pH	3.66
Starch (% DM)	32.7
NDF (% DM)	39.1
Yeast (log cfu/g)	4.94
Mould (log cfu/g)	6.60
Anaer. spore (log cfu/g)	3.70



Microbiological quality of corn silage at different levels of spoilage

	Good silage	Deteriorated silage	
		Warm	Mouldy
Visible mould	NO	NO	YES
Temperature (°C)	20.2	47.5	25.9
dT (°C)	-2.5	24.1	3.1
DM losses (%)	5.0	13.1	39.5
pH	3.51	4.95	7.03
Yeast (log cfu/g)	3.05	7.45	6.42
Mould (log cfu/g)	2.09	4.34	9.23

(Tabacco et al., 2011)

Depressed quality in deteriorated maize silage

	Good silage	Deteriorated silage	
		Warm	Mouldy
Ash, % DM	3.17	3.44	4.75
NDF, % DM	41.0	45.7	52.6
ADF, % DM	21.1	23.7	32.4
Starch, % DM	36.6	35.5	29.6

(Tabacco et al., 2011)

New tools to improve monitoring of silage quality at feed-out for precision agriculture

Characteristics to be monitored	Tools	Application for precision feeding systems
Temperature	Temperature sensors	New generation balers
pH	Infrared thermography	TMR mixer wagon
Yeast and mould	Wireless sensor nodes	Feeding robots fully automated
Sporeformers	Portable pHmeter	
Pathogens	Portable NIRS	
Mycotoxins		
DM losses		
Fermentative products		
Nutritive quality		

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

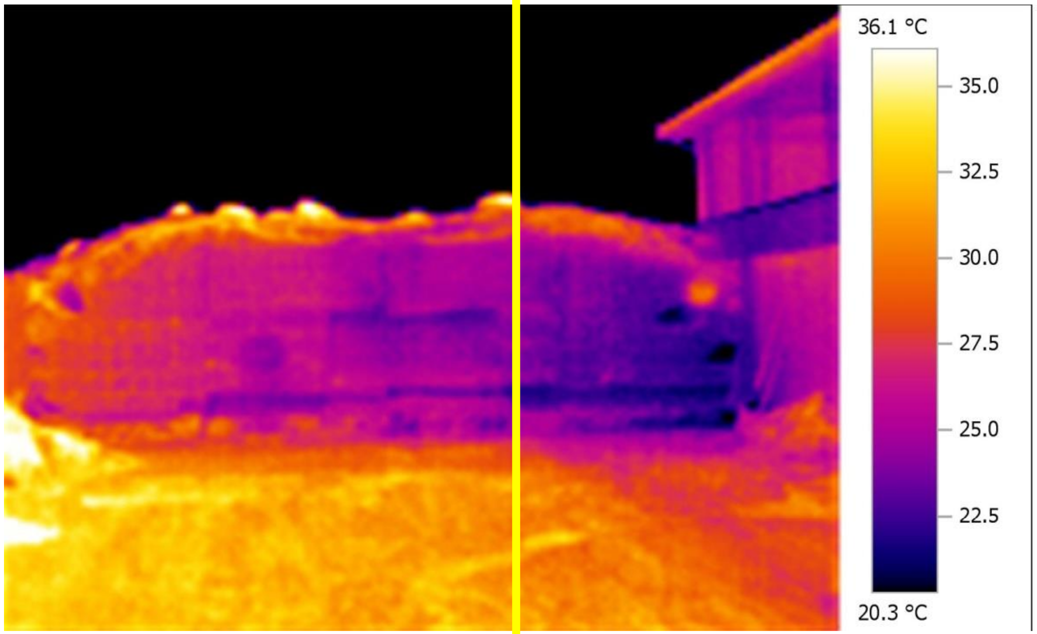
Strengths

- 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

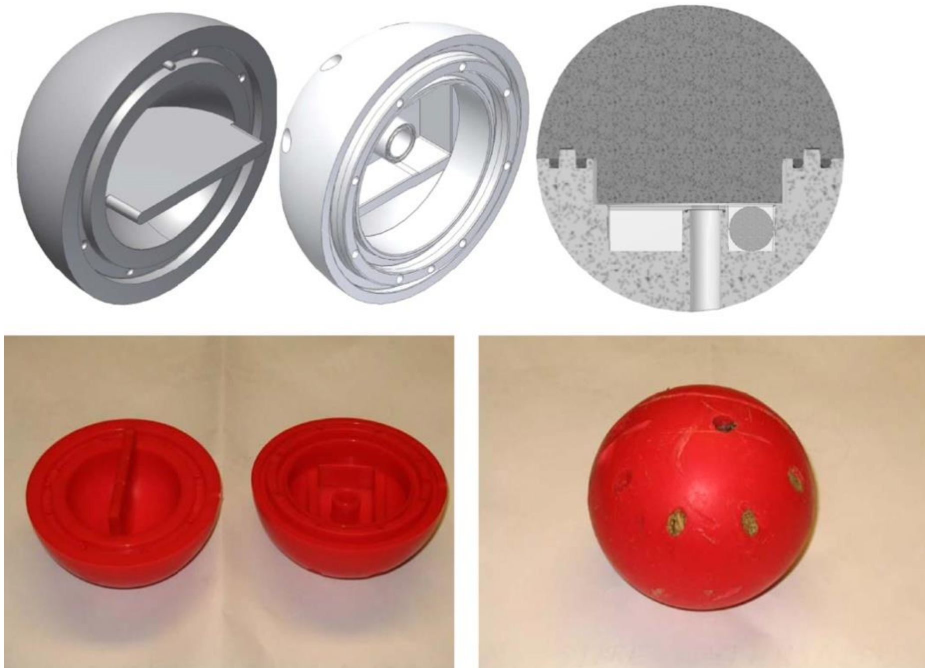
Strengths

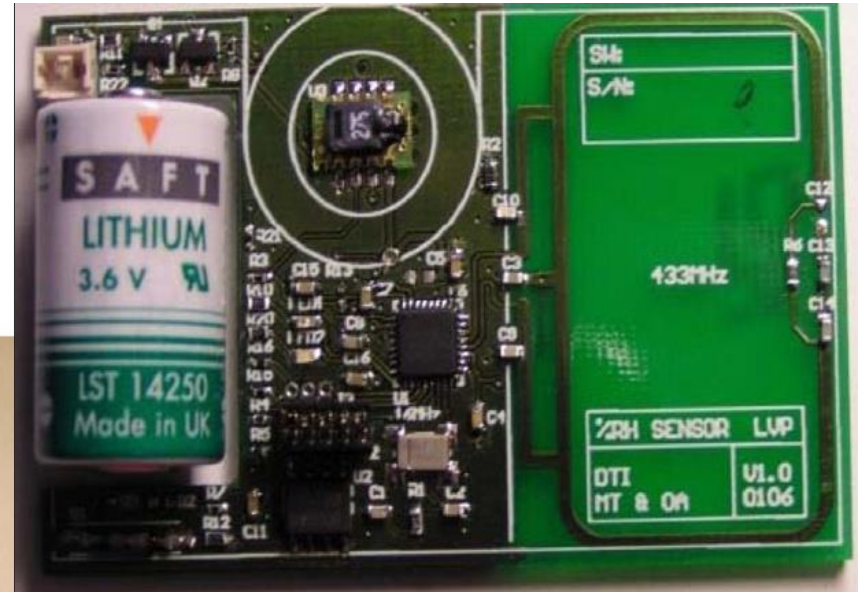
- Buried in the mass at ensiling
- Follows evolution of temperature during storage and feedout phase
- Possibility of recording long period of data (up to 1 year)

Weaknesses

- Experimental purpose only
- Local measurement only
- Difficult to retrieve in the silage

Wireless sensor nodes (Green et al., 2009)





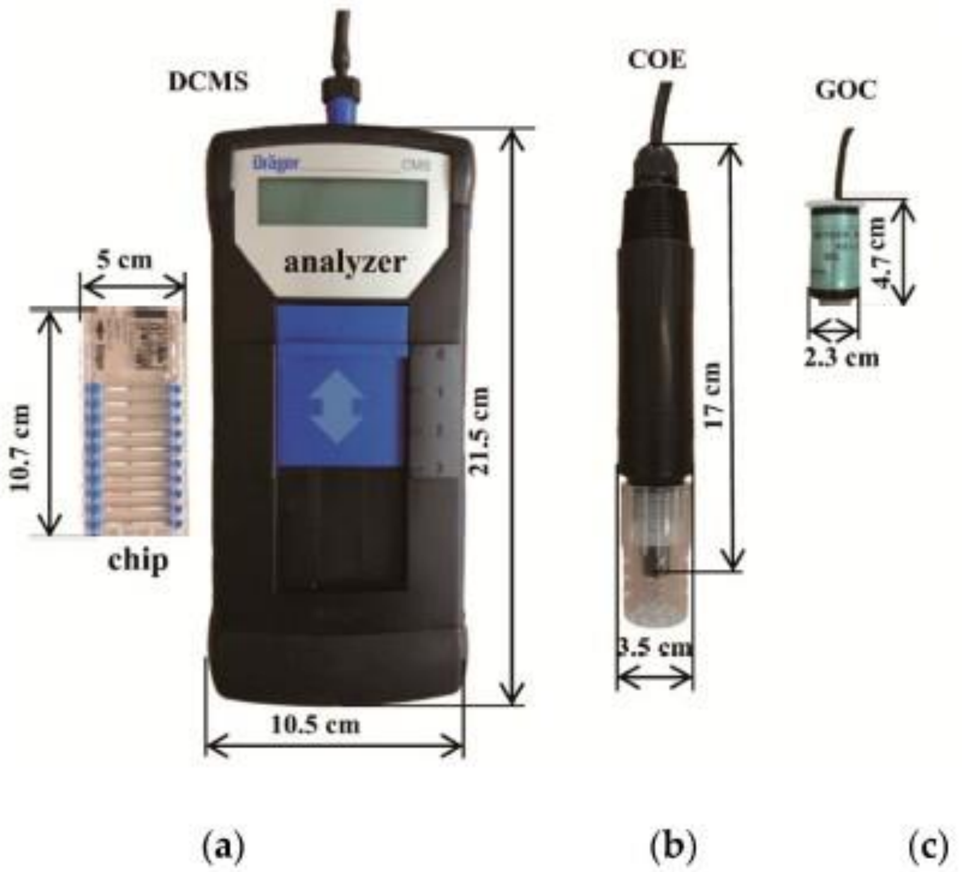
Strengths

- 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)

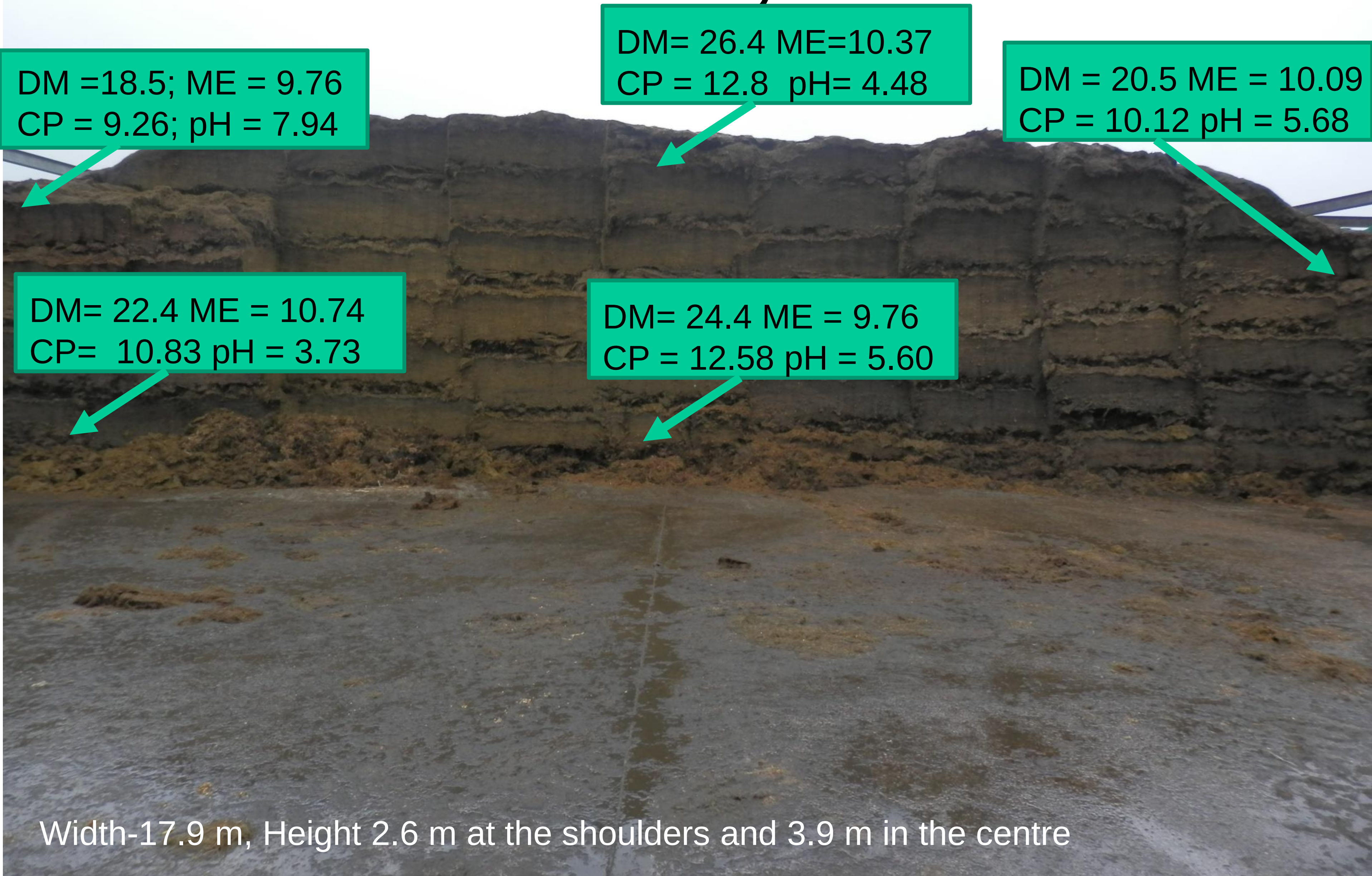


Dimensions of oxygen (O_2) sensors, (**a**) Dräger chip measurement system (DCMS); (**b**) the Clark oxygen electrodes(COE); (**c**) galvanic oxygen cell (GOC)

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



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 ?