# The Future of Ensiling: Challenges and Opportunities

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# Scope of this Presentation

We highlight some challenges and opportunities for the future of ensiling

We pose some questions…..but we may not give you the answers

We aim to stimulate future research to improve ensiling and its contribution to meeting nutrient requirements of productive livestock

# Challenges

1. Mechanisation
2. Silos
3. Hazards to animal and human health
4. Global warming
5. Silage bio-refineries
6. Silage analysis

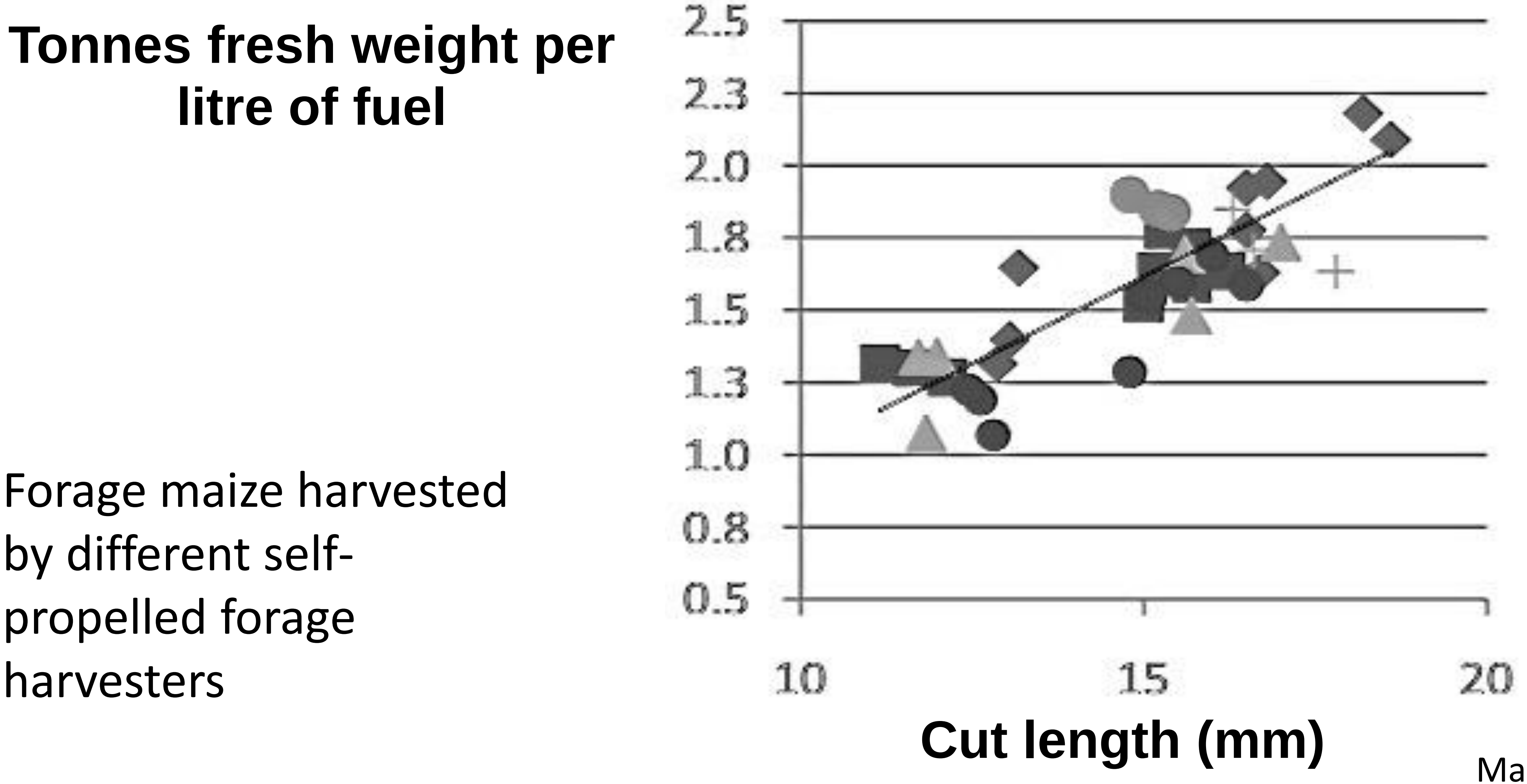
# 1. Mechanisation

**Have we reached the limit to forage harvester size and chopping capacity?**

- Rapid harvesting can compromise silo packing efficiency
- Trend to increase chop length, e.g. shredlage

**Challenge: How to increase efficiency without increasing size of machine?**

# Particle Length and Fuel Use




Forage maize harvested by different self-propelled forage harvesters

Marsh, 2013

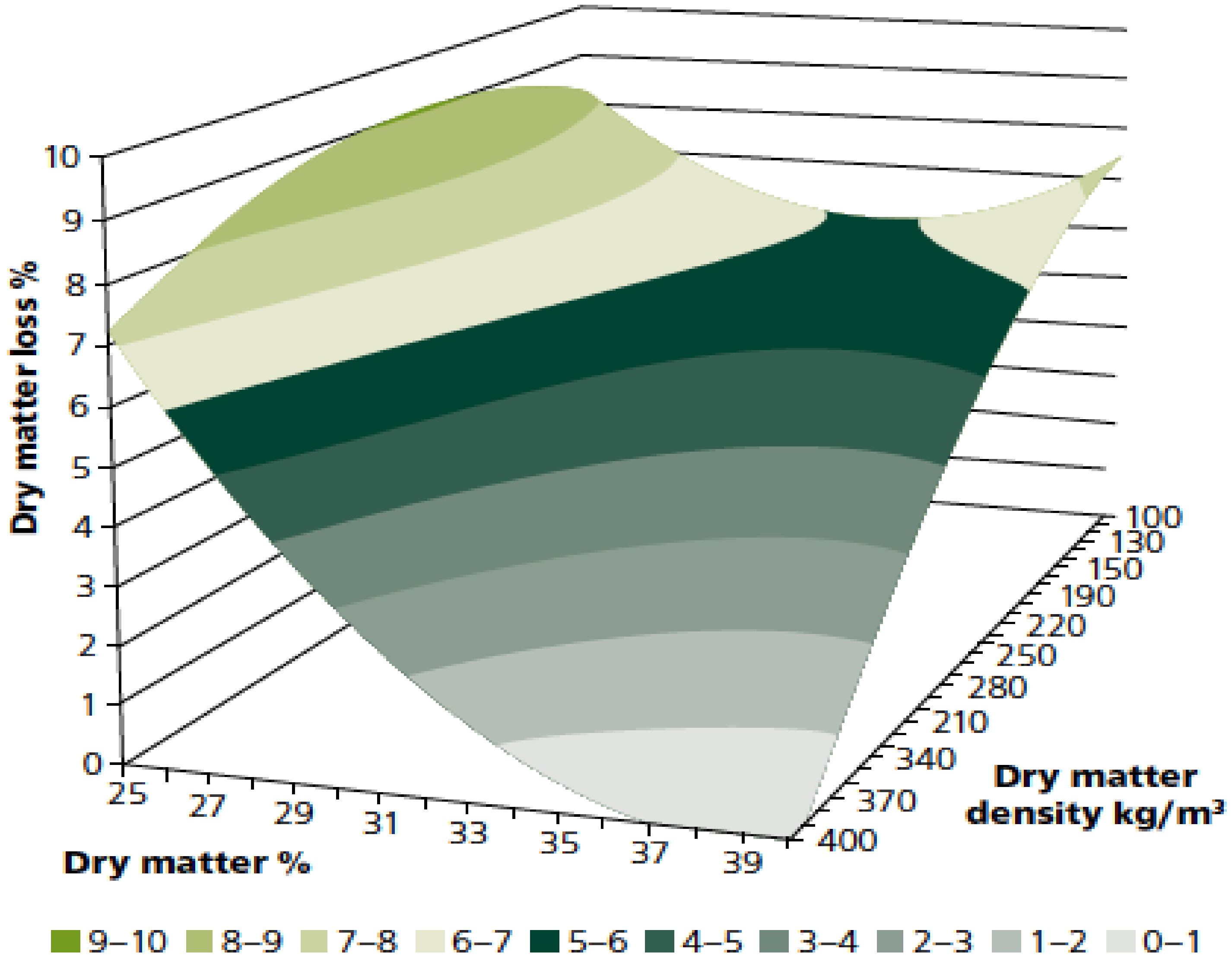
# 2. Silos

**Many silos are:**

**Too old**
**Too small**

- Crop packing density has a large effect on loss of dry matter (DM) during storage
- Survey of 149 farm bunkers filled with whole-crop maize revealed only 36% were packed to more than 240 kg DM/$m^3$ (Andrieu and Demey, ISC, 2015)
- DM loss is related to both DM density and DM%

# Density and In-Silo Loss




Griswold, 2010

# 3. Hazards to Animal and Human Health

- The silage fermentation is only partially controlled
- Hazards to health include:
  - *Clostridium botulinum*, *Listeria monocytogenes*, Shiga-toxin producing *Escherichia coli*
  - *Mycobacterium bovis*
  - *Cryptosporidium parvum*
  - Toxins produced in field and in silo by fungi, e.g. *Fusarium*, *Aspergillus*, *Penicillium*

**Challenge: How do we know when livestock are suffering from a silage-related disease?**

Need new animal-based diagnostics than are rapid, non-invasive, and sensitive

# 4. Global Warming

- **The perfect storm**:
  - Rising global demand for livestock products
  - Limited land on which to grow human food
  - Large quantities of human-edible food used for livestock feed
  - Need to maintain biodiversity and landscape value
  - Challenge to reduce livestock emissions of greenhouse gases (GHG)
- **Huge range in carbon footprint between different livestock systems**
- **Few data on impact of different methods of crop storage on GHG**
  - Volatile organic compounds (VOC) from silage are ozone precursors and contribute to global warming. Research in Germany has shown elevated VOC with delayed silo sealing and reduced VOC following addition of sodium benzoate and potassium sorbate.

# Impact of Global Warming on Crops

**Challenge of increased $CO_2$, temperature and reduced water**

- Maximum photosynthetic capacity of temperate ($C_3$) grasses (e.g. *Lolium* spp) is 27$^{o}$C
- $C_4$ grasses (e.g. maize) are adapted to higher temperatures and restricted water availability
- Higher $CO_2$, higher temperature, reduced water:
  - Increased non-structural carbohydrates and phenolics in all species
  - Increased lignin in legumes
  - Decreased tannins in grasses
  - No effects on structural carbohydrates, protein, lipid or mineral levels (AbdElgaward et al., 2014)

# Impact of Global Warming on Silage

- Higher ambient temperature → faster fermentation
- BUT optimal temperature for lactic acid bacterial growth = 35$^{o}$C
- AND Clostridia will grow at up to 45$^{o}$C
- AND Maillard reactions occur above 35$^{o}$C
- AND higher silage temperatures during feed-out increase $O_2$ ingress into silage mass and growth of spoilage organisms

**Challenge: Study silage fermentations and aerobic spoilage at temperatures above 40$^{o}$C**

# 5. Silage Bio-Refineries

- Combine harvester separates high value grain from low value straw
- Forage harvester does not separate crop components at harvest
- Limited research into forage (i.e. whole-crop) fractionation before or after ensiling

**Challenge of adding value to forage crop components, e.g. production of essential amino acids**

# 6. Silage Analysis

- Sampling error is the largest source of variation in maize silage composition within a silo (St-Pierre and Weiss, 2015)
- Sample frequently, send multiple sub-samples to the laboratory, average the results and use only until the next set of results is available
- Do not create rolling averages based on historical analyses

**Challenge: Can we predict animal responses to silage inoculation from conventional silage analysis?**

# Milk Response to Silage Inoculation

| Meta-Analysis | Datasets | Crops | Average response (kg/day) |
|---|---|---|---|
| Keady (1998) | 13 | Perennial grasses | +1.0 |
| Kung & Muck (1997) | 36 | Various forages | +0.65 |
| Oliviera et al. (2017) | 31 | Various forages | +0.37[1] |

[1] Response was unaffected by type of crop.  Inoculation had no significant effect on fermentation parameters in maize, sorghum and sugarcane silages

# Possible Mechanisms to Explain Animal Responses to Inoculation

| |
|---|
| ↓ Carbon loss as $CO_2$ in silo |
| ↓ Proteolysis in silo |
| ↑Digestibility |
| ↑ Intake of dry matter and energy |

**Challenge: If effects of inoculation are mainly in the rumen, are we measuring the right things?**

# Opportunities

1. Advances in crop harvesting and ensiling
2. Total Mixed Ration silages
3. Additives to improve silage hygiene and increase nutrient availability
4. Early indicators of aerobic instability
5. Metabolomics and metabonomics
6. Artificial intelligence and machine learning

# 1. Advances in Crop Harvesting and Ensiling

- Global positioning systems, field maps, sensors, cameras and actuators relieve the operator from routine driving and implement control

Example: fill control on the forage harvester detects trucks and automatically moves the harvester spout to more precisely fill trucks without spilling forage

# Dawn of driverless operations on the farm

Possibilities:

- Harvesting
- Transporting forage from field to silo
- Spreading and packing in the silo

**Multiple Agricultural Robotic Swarms planting maize**
Fendt, 2018

# 1. Advances in Crop Harvesting and Ensiling

- Global positioning systems, field maps, sensors, cameras and actuators relieve the operator from routine driving and implement control
- Driverless vehicles might soon be carrying crop from field to silo
- Robotic silo packing – improved safety
- Novel methods for assessing silage density
    - Weigh the crop on arrival at the silo
    - Use lasers to determine volume?
- Re-usable covering materials
- Edible film covers?

Agridek, 2018

# 2. TMR Silages

- Wet by-products are commonly used in livestock diets but often are unstable unless used rapidly.
- Co-ensiled by-products with forages to produce total mixed ration (TMR) silage had good fermentation characteristics and enhanced aerobic stability (Nishino et al. 2003).
- Larger ‘feed stations’ could produce ensiled TMR for smaller local livestock farms with lower storage losses

**Opportunity: Determine optimal mixtures and discover reasons for enhanced aerobic stability**

# 3. Additives to Improve Silage Hygiene and Increase Nutrient Availability

- Historically, additives were employed to:
  - Increase dominance of lactic acid bacteria (LAB) – LAB inoculants
  - Inhibit clostridial growth – nitrites
  - Restrict yeast and fungal growth – organic acids (propionates, acetates, sorbates and benzoates), *L. bucheri*

# 3. Additives to Improve Silage Hygiene and Increase Nutrient Availability

**Opportunities to improve silage hygiene:**

- Bacteriocins to inhibit undesirable bacteria – clostridia, listeria, enterobacteria
- Microorganisms, enzymes or binding agents to reduce or detoxify mycotoxins on crops at ensiling
- Other toxins?

# 3. Additives to Improve Silage Hygiene and Increase Nutrient Availability

**Opportunities to increase nutrient availability:**

- Improve fibre digestibility through enzymes that hydrolyse ether and ester cell wall bonds in the silo that are difficult for rumen microorganisms to attack
    - Inoculation with *L. buchneri* strain that produces ferulic acid esterase
- Tannins or polyphenol oxidase to reduce proteolysis in the silo
- Acidic proteases to degrade zein/prolamine proteins in maize kernels in the silo so that starch is more digestible.

# 4. Early indicators of aerobic instability

- If the lactate-assimilating yeast count is $>10^5$ colony forming units per gram of silage, then silage is likely to deteriorate within 24 h.
- BUT sending a sample to the lab for yeast count is not practical
- AND rapid tests for human pathogens have been developed

**Opportunity: Can a rapid and safe test for yeasts in silage be developed?**

# 4. Early indicators of aerobic instability

- Temperature 200 mm behind the exposed face *minus* temperature 400 mm behind the face is positively correlated with pH, yeast and mould count (Borreani and Tabacco, 2010).
- Are these results repeatable in different climates?

**Opportunity: Can a safe system to probe for temperature at different depths from the face be an early indicator of aerobic instability?**

# 5. Metabolomics and Metabonomics

- **Metabolomics**: mass spectrometry in conjunction with other techniques to quantify a wider range of metabolites than the primary acids and alcohols in silage.
- Why? The major silage fermentation products have not helped us predict how livestock will utilise silage. Perhaps other metabolites will.

# 5. Metabolomics and Metabonomics

| Metabolite | Control | L. plantarum | L. buchneri |
|---|---|---|---|
| 2,3-Butanediol | 87 | 171 | 340 |
| 2-Aminobutyric Acid | 61.5 | 12.5 | 25.1 |
| 4-Aminobutyric Acid | 112 | 169 | 272 |
| Adenine | 2.6 | 26.2 | 21.0 |
| Cadaverine | 192 | 22 | 101 |
| Malonic Acid | 2.2 | 10.9 | 7.7 |
| Phenethylamine | 3.6 | 0.3 | 1.2 |
| Tyrosine | 3.2 | 16.8 | 98.4 |
| Glutamic Acid | 77 | 39 | 29 |

Relative concentrations in lucerne silage (Guo et al., 2018)

# 5. Metabolomics and Metabonomics

**Opportunity: Use metabolomics with microbiome data to better understand the changes during ensiling and the microorganisms involved. Future studies need to concentrate on the initial 4 to 7 d of ensiling, when most of the fermentation action is occurring.**

# 5. Metabolomics and Metabonomics

- **Metabonomics**: Quantitative measurement of metabolic responses in the animal to changes associated with external factors including disease stimuli such as mycotoxins in silage
- Current mycotoxicosis research (www.bovmycotox.co.uk) uses hydrogen nuclear magnetic resonance, mass spectroscopy and high-performance liquid chromatography to determine metabolite profiles, pattern recognition and metabolite identification in samples of cells, tissues and body fluids from animals given diets containing mycotoxins. Objective: Improved diagnosis.

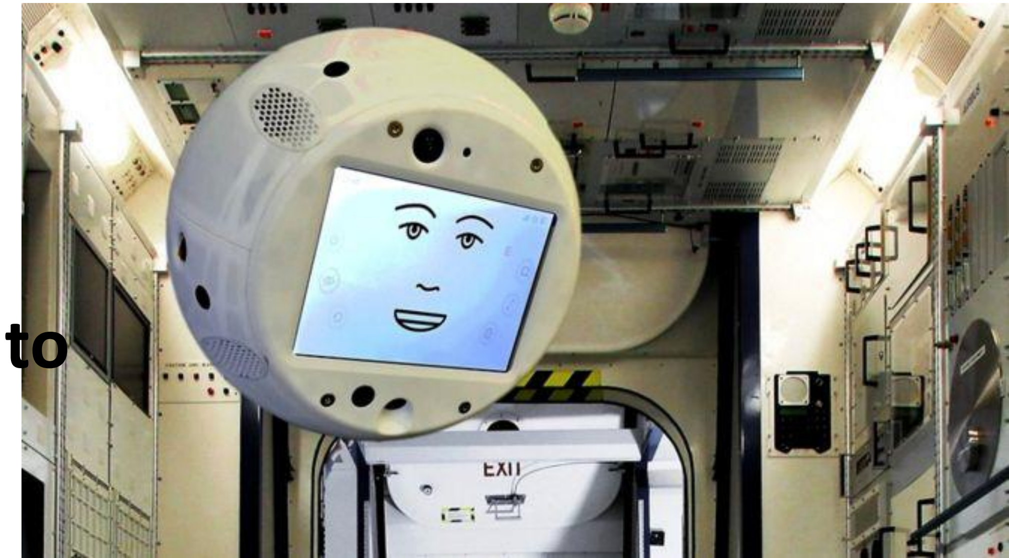
**Opportunity: We are now on the cusp of unlocking microbial and metabolic interactions between silage and animal**

# 6. Artificial intelligence and machine learning

Large quantities of data are generated by microbiome, metabolomic and metabonomic research on crops, silages and animals given diets based on silages

**Opportunity: Can we mine the world's scientific data to identify the most important factors affecting silage fermentation and its value to livestock?**

**Opportunity: Smart farming and artificial intelligence can be applied to silage making to optimize the process**



# A Vision of Ensiling in 2050

- Drone or satellite information on variation in crop composition and quality
- Robotic identification and harvesting according to DM and quality, allowing for changes in harvesting sequence and additive use
- Robotic transport of crop from field to silo
- Specialised equipment for forage distribution across the silo surface
- New additives to improve fibre and nutrient availability
- Additives to reduce or eliminate mycotoxins and other microbial toxins
- Re-usable and/or edible silo covers
- Robotic emptying of silos; sensors to recognize spoiled silage and discard it so that it is not included in the TMR

# Conclusions

1. Changes at one stage in the ensiling process can produce challenges at subsequent stages
2. Challenges create research opportunities
3. New developments in automation offer new opportunities for improving efficiency
4. Responses to external factors can be inexplicable by conventional silage analyses – new molecular techniques offer great opportunities to solve the challenge of why some silages under-perform
5. Ensiling is such an important global process. It deserves continued, sustained, multidisciplinary research to help users realise its full potential

**THANK YOU FOR GIVING US THIS CHALLENGE ……AND OPPORTUNITY!**