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# The frontiers of forage mechanization at the service of efficient livestock systems in a Climate Smart Agriculture strategy

*Some reflections to follow a fruitful roadmap*

**33rd Members' Meeting of the "Club of Bologna"**

**"The future horizons for Ag-Mechanization"**

*November 9-10, 2024*

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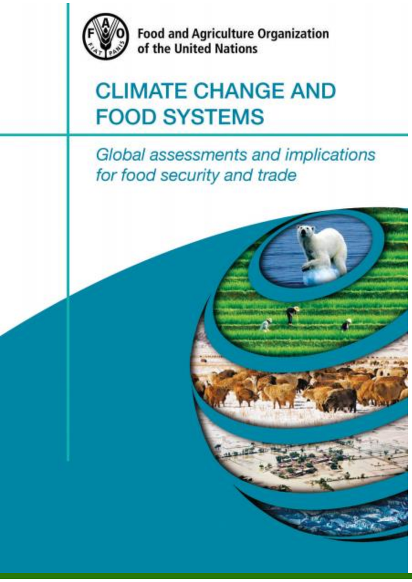
# 2015: Towards a Climate-Smart Agriculture (CSA):

- **CSA** : new global paradigm proposed by **FAO (2015)** to face the primary production problems in a world subjected to deep (negative) changes
- **CSA→Innovative guidelines** compatible with the needs of **food security** and **environmental sustainability** in contexts increasingly 'stressed' by **adverse climate change**
  - **sustainable increase in agricultural productivity and income for workers in the sector**
  - **adaptation to climate change through the acquisition of new forms of resilience**
  - **reduction of greenhouse gas emissions where possible.**




- **Implementation strategies** vary from country to country
- … and what about industrialized countries? (USA, EU)

*FAO, 2015.* **Climate change and food system - Global assessment and implications for food security and trade**. *Ed. by A.Elbehri, Economic and Social Development Department, Food Agriculture Organization of the United Nations (FAO), I4332, pp.357.*

## CSA in industrialized countries

- CSA matches the need to develop **technological innovations** for a **rational management** of production systems

- Focus on: **1)** *wastage control (energy- and input-saving)*, **2)** *narrow profit margins* **3)** *rationale technology management,* better if associated to **scheduled maintenance** plans

  - New production systems with low costs and reduced environmental impacts (relevant roles for hard- and bio-technologies);
  - Adoption of new forms of **advanced management** *to improve product quality, work efficiency, cost reduction* through **innovative control actions** (**Management Information Systems**)
  - Greater attention to **safety** and **comfort** conditions for workers
  - Ensuring **reasonable** forms of **transparency** in the results of farm management through **product and process certification**

# CSA → To develop technological innovations for …

- Improve **FARM MANAGEMENT** MN

- Integrating **TRACEABILITY** functions into day-to-day management activities (**product and process certification**) TR

- Promoting production processes oriented towards **ENVIRONMENTAL SUSTAINABILITY** ENV

- Apply innovative **TECHNOLOGIES FOR AUTOMATING** controls functions in **field processes** (*site-specific farm management, target farming)* SFM

# What is PA?

- Exhaustive **definition** provided by **NRC** (1997): **management strategy** that uses **information & communication technologies** (**ICT**) to collect **data** from *multiple sources* in view of their later use in **decisions** concerning (*field*) *production activities*

- **Smart Agriculture** → **Management Quality** → **Ability to make decisions** based on **targeted information**, previously collected through a **global monitoring** of production processes



## Precision Agriculture

- Relevant analogies with the orginal concept of **Industry 4.0 ...**

# COMMON TARGETS

**INDUSTRY 4.0** — **PRECISION AGRICULTURE**

| Industry 4.0 | Precision Agriculture |
| --- | --- |
| Process Digitization | Informations systems for management and resource planning (**ERP evolution**) |
| Automation | For both **monitoring** the production lines and improving **process productivity** |
| Iperconnectivity | **Cybernetic approaches** |
| Treatment of huge amount of data | **Big DATA** |
| Quick data interpretation | **Machine Learning**<br>Adding INFORMATION to data achieved for targetted and **quality decision making processes** |

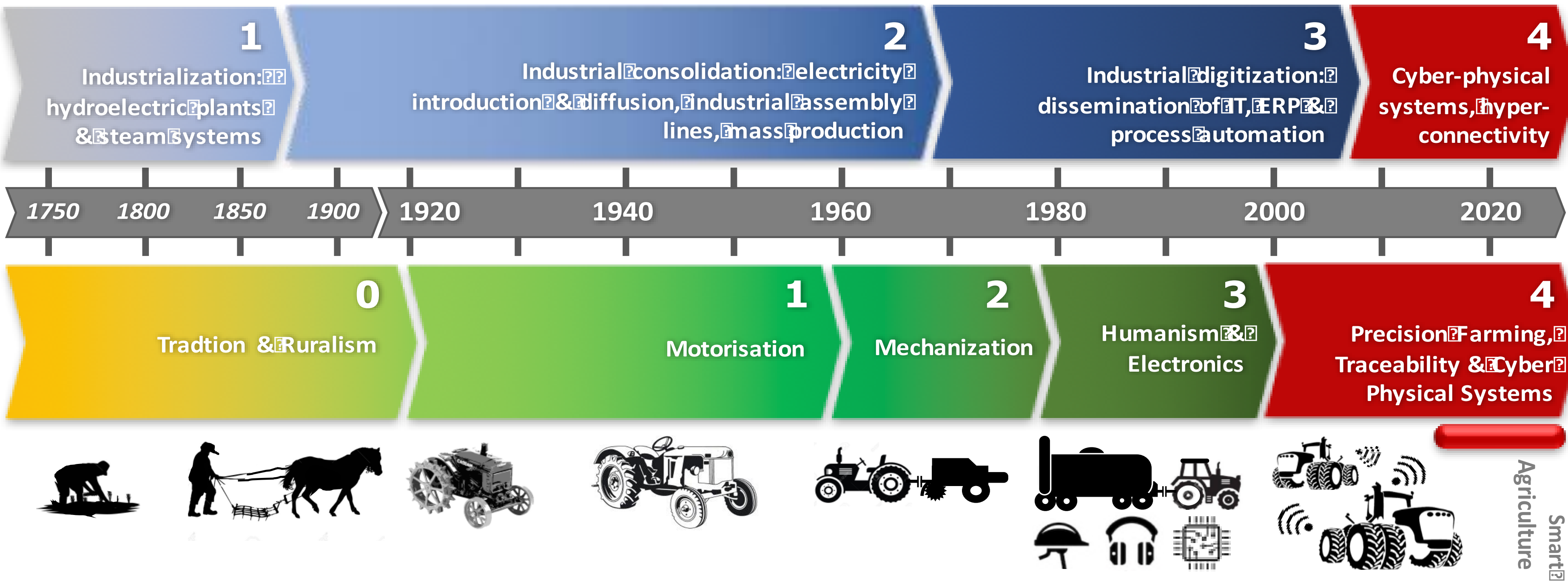
IoT

IoS

# COMMON TARGETS

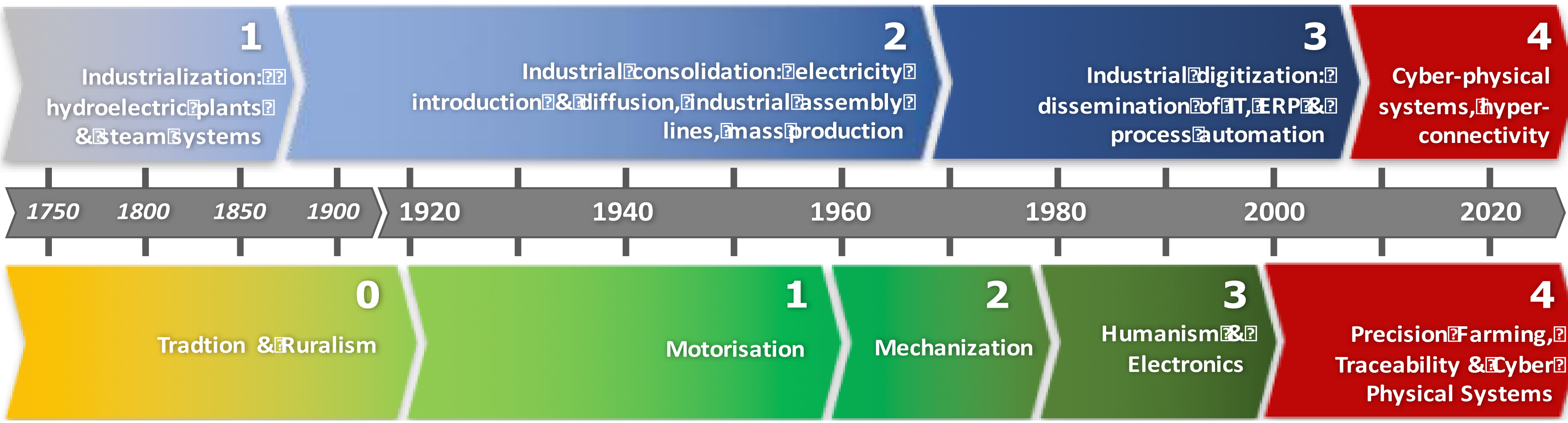

| | |
|---|---|
| **Responsible innovations...** | Not only or primarily aimed at increasing cost-efficiency or maximising profit, but also at increasing **prosperity for all actors involved**: *investors, workers, consumers, society, and the environment* |
| **Human-centric** | Core-human needs and interests at the heart of the production process (**social dimensions & TRAINING**) |
| **Environmental sustainability** | Respecting **planetary** boundaries…. |
| **Resilience** | Higher degree of **robustness in production**, to better contrast **disruptions**, and to provide and support critical infrastructure in times of crisis. |

# AGRICULTURE vs. INDUSTRY




- Consolidation of electronics &automation (**site-specific control**).
- **Sensors in monitoring activities** and on board tractor **positioning systems**
- **Traceability** and **certification**
- **Communication** protocols (CAN, ISOBUS, Wi-Fi, Bluetooth, etc.), to foster process **connectivity** and M2M communications, with IoT and IoS
- Incremented interest in management **digitalization** and use of **integrated information systems (IIS)**, especially in large farms, including **cloud and fog computing** platforms

# FOCUS ON FORAGE PROCESSES




*Focus mainly on FLAT lands*

*Focus on STEEP lands*

**Effort intensity in innovating forage mechanization and related conservation processes**

*Several proposals for **radical innovations** (not all of which have been then confirmed)*

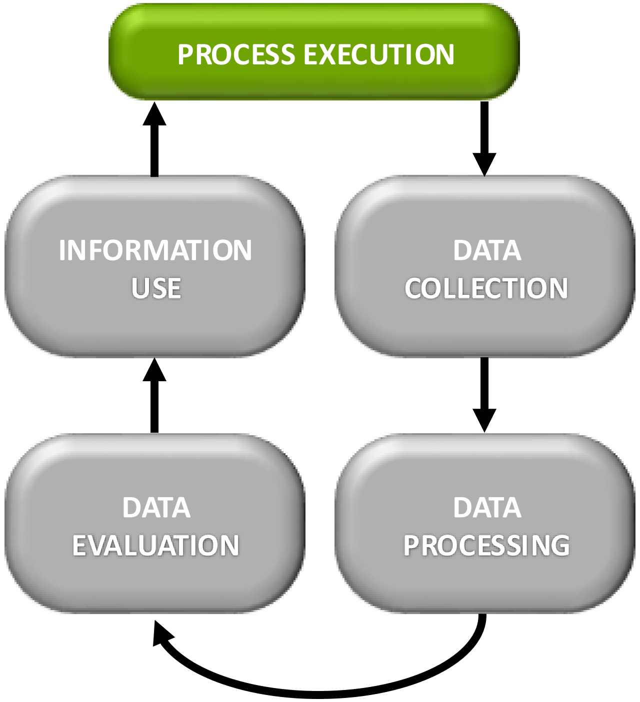
*Persistence of **incremental innovations** (related to punctual aspects of the production chain)*

# Some key points…

- Comprehensive SA applications require a real **paradigm shift** with deep impacts in the **FARM Management and Information System**

- Difficulties for agriculture that has to recover an **IT gap** in its evolution (absence of the analogous **Ind. 3.0** → **ERP** = *Enterprise Resource Planning* → ***Integrated Information Systems***)

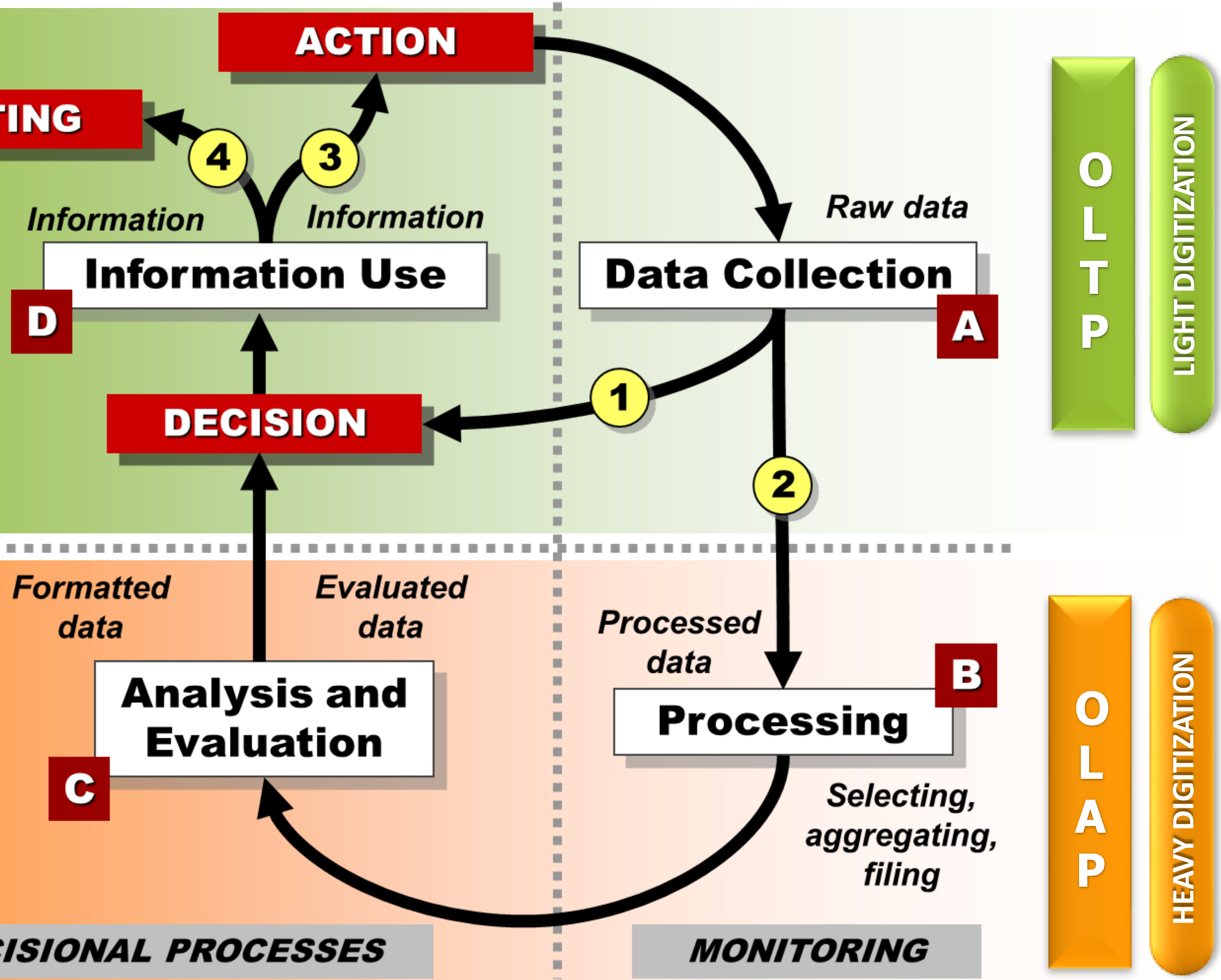
- Designing a new generation of **Farm Management and Information Systems** (**FMIS**), tailored to the *limitations* and *peculiarities* of agricultural processes, emphasising the **conceptual role** that each component must play along the transformation cycle: **data → information →decision**



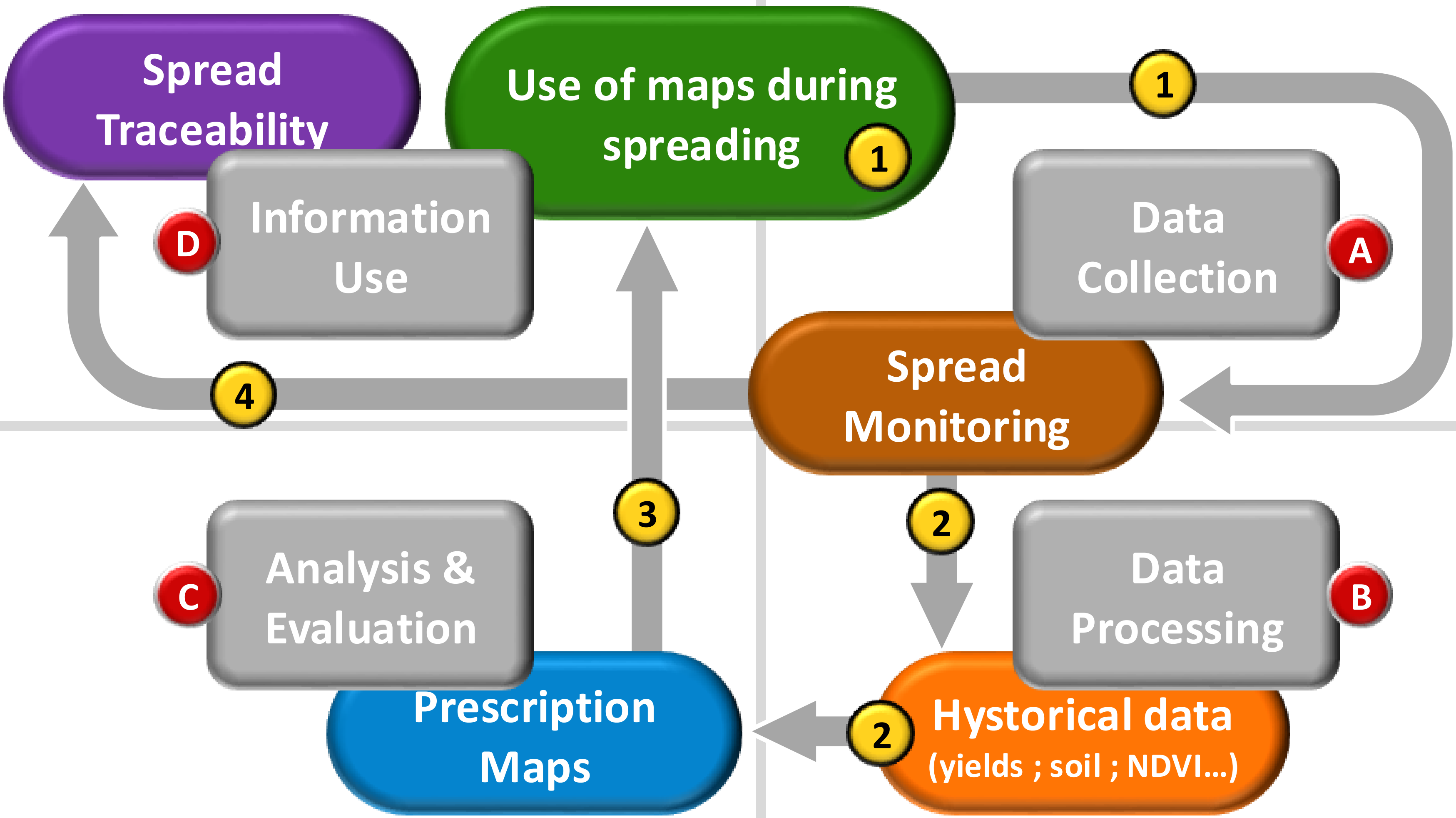
# FIS CONCEPT

- SINGLE facts, events and process
- PUNCTUAL vision
- SPECIFIC analysis & control actions
- STANDARD procedures

- AGGREGATE facts, events and process
- GLOBAL vision
- GLOBAL analysis & control actions
- FLEXIBLE procedures



# Site-specific fertilization of grassland (within the FIS...)

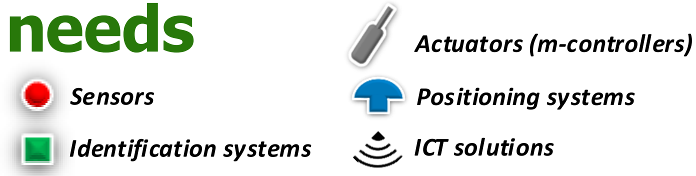


# «DIGITAL» IMPLICATIONS

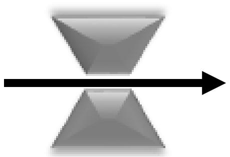
- (green) Strenght/Opportunity
- (red) Weakness/Threat
- (grey) Neutral

| | INDUSTRY | CROP PRODUCTION | ANIMAL HUSBANDRY | CONTRACT. |
|---|---|---|---|---|
| **Financial and economic solidity** | green, green, green | red, red, red | green, green | green, green, green |
| Work contexts in **contained**, **limited** and highly **controllable** spaces | green, green, green | red, red, red | green, green, green | red, red, red |
| **Repeatable** production processes | green, green, green | red, red, red | green, green | green, green, red |
| Professional staff and **highly skilled** technician | green, green, green | red, red, red | green, green, red | green, green, red |
| Internal availability of **ICT skills** | green, green, green | red, red, red | red, red | green, red |

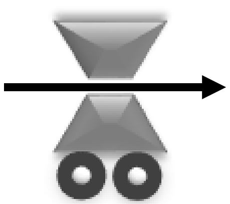
# Supply chain symbols & control needs



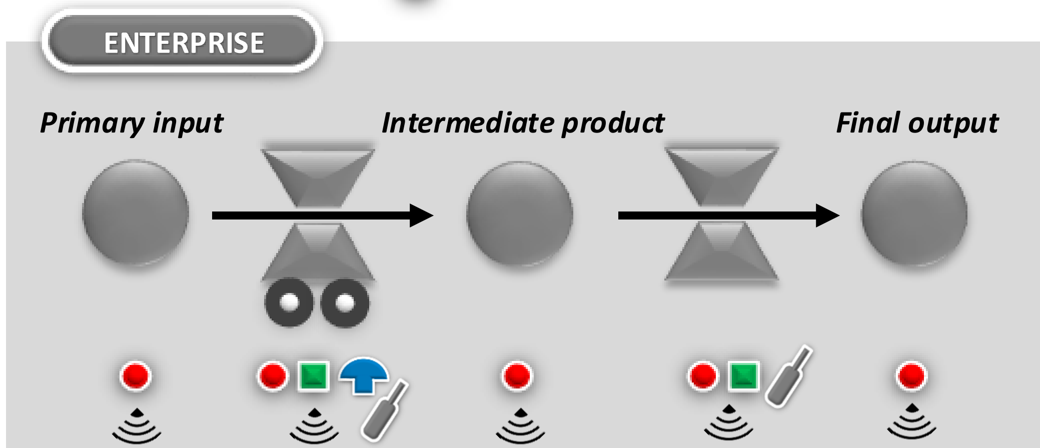

Input/Output materials (including ENERGY) that are considered as the main target of a process



Stationary processes, requiring one or more fix plants treating a continuous flux of material



Mobile processes, requiring a moving power generator (eg. a tractor) combined with one or more working tools treating a flux of materials (transports, spreaders…) generally discontinuous




- Timestamp
- Mass/Volumes
- Chemical properties
- Physical properties

- Timestamp
- Position (site of work, paths)
- ID Power Unit
- ID tools
- *(ID Worker)*
- Work specificat.

- Timestamp
- Mass/Volumes
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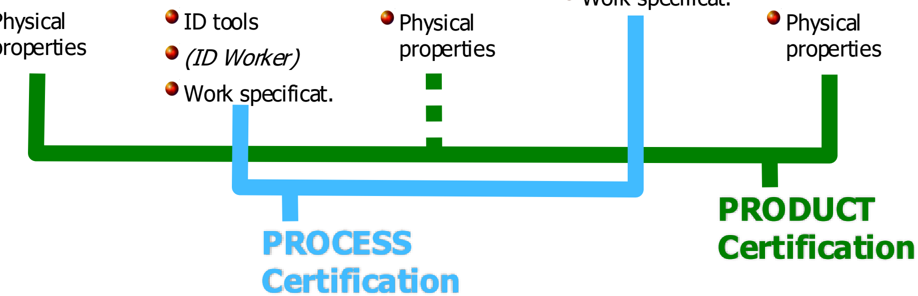
- Physical properties

- Timestamp
- ID Power Unit
- Fluxes
- Work specificat.

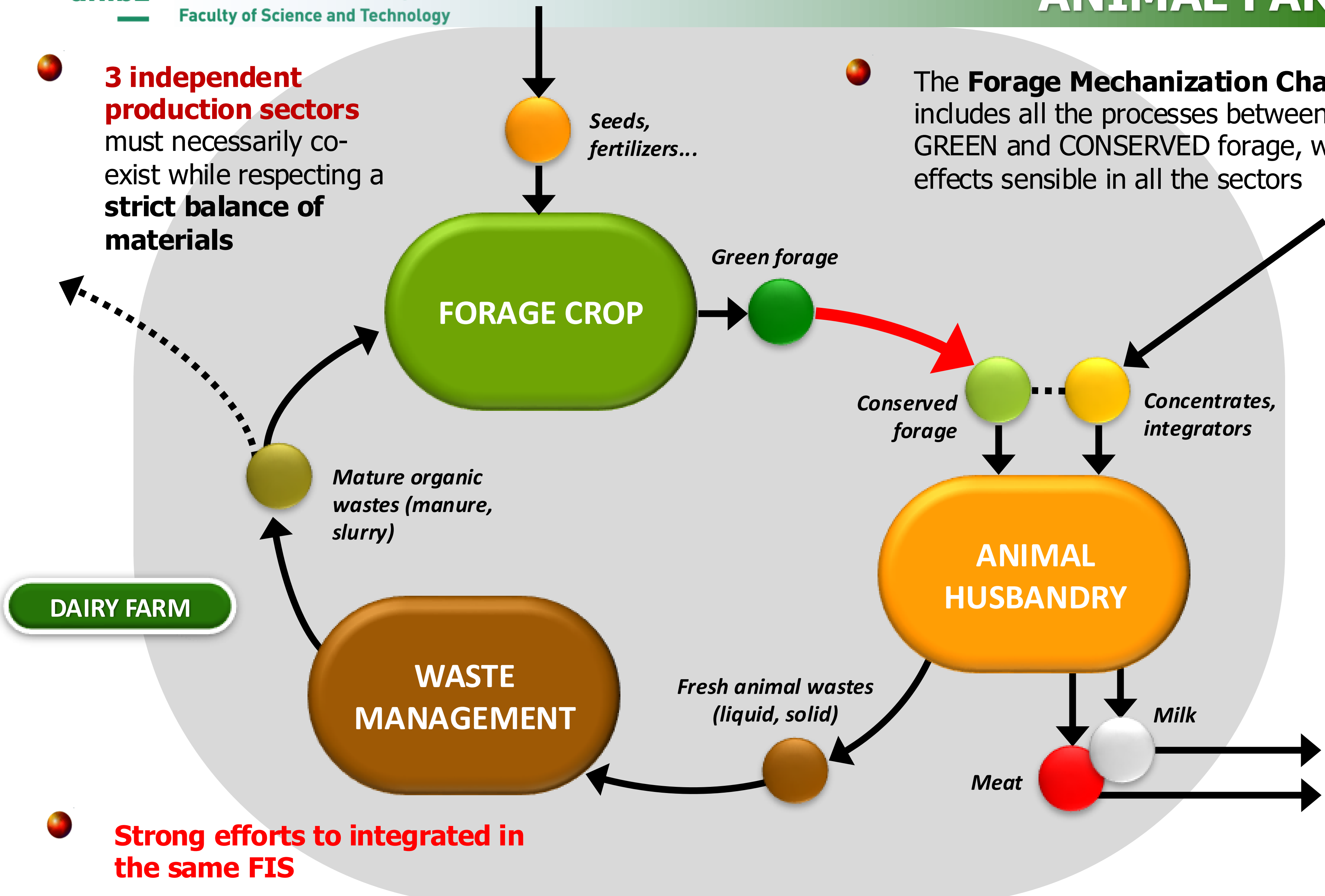
- Timestamp
- Mass/Volumes
- Chemical properties
- Physical properties



# ANIMAL FARM

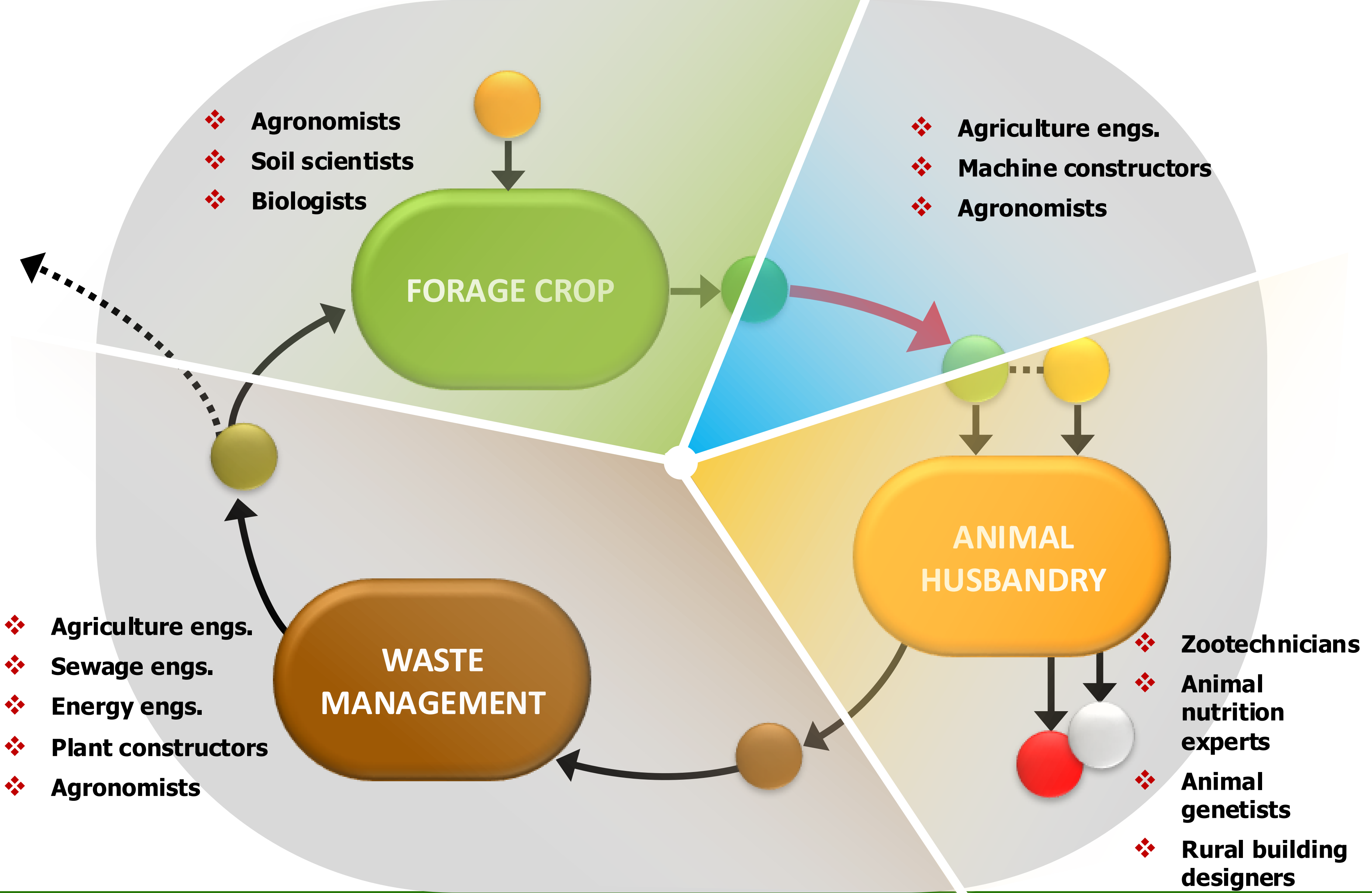
- **3 independent production sectors** must necessarily co-exist while respecting a **strict balance of materials**

- The **Forage Mechanization Chain** includes all the processes between GREEN and CONSERVED forage, with effects sensible in all the sectors

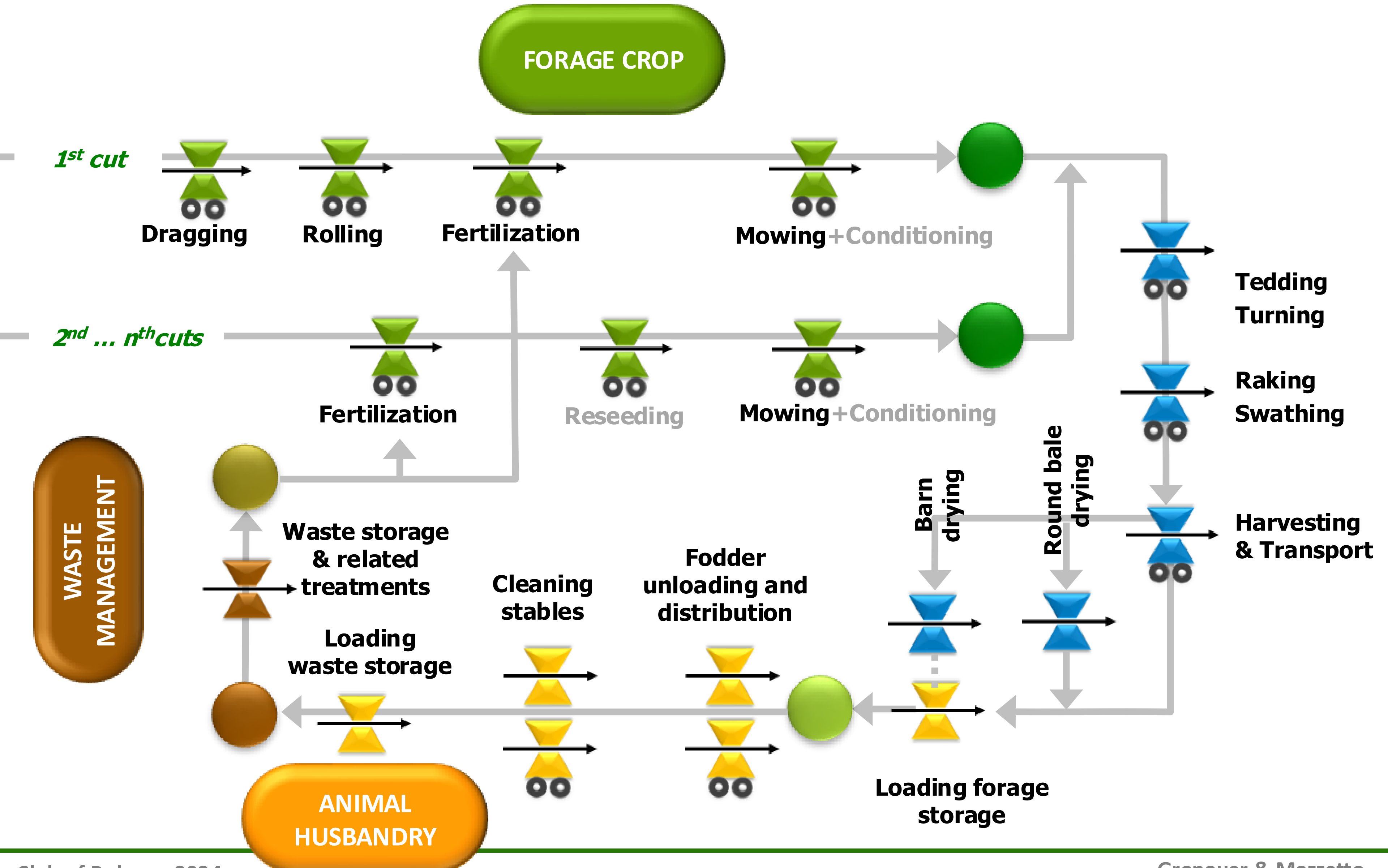



- **Strong efforts to integrated in the same FIS**

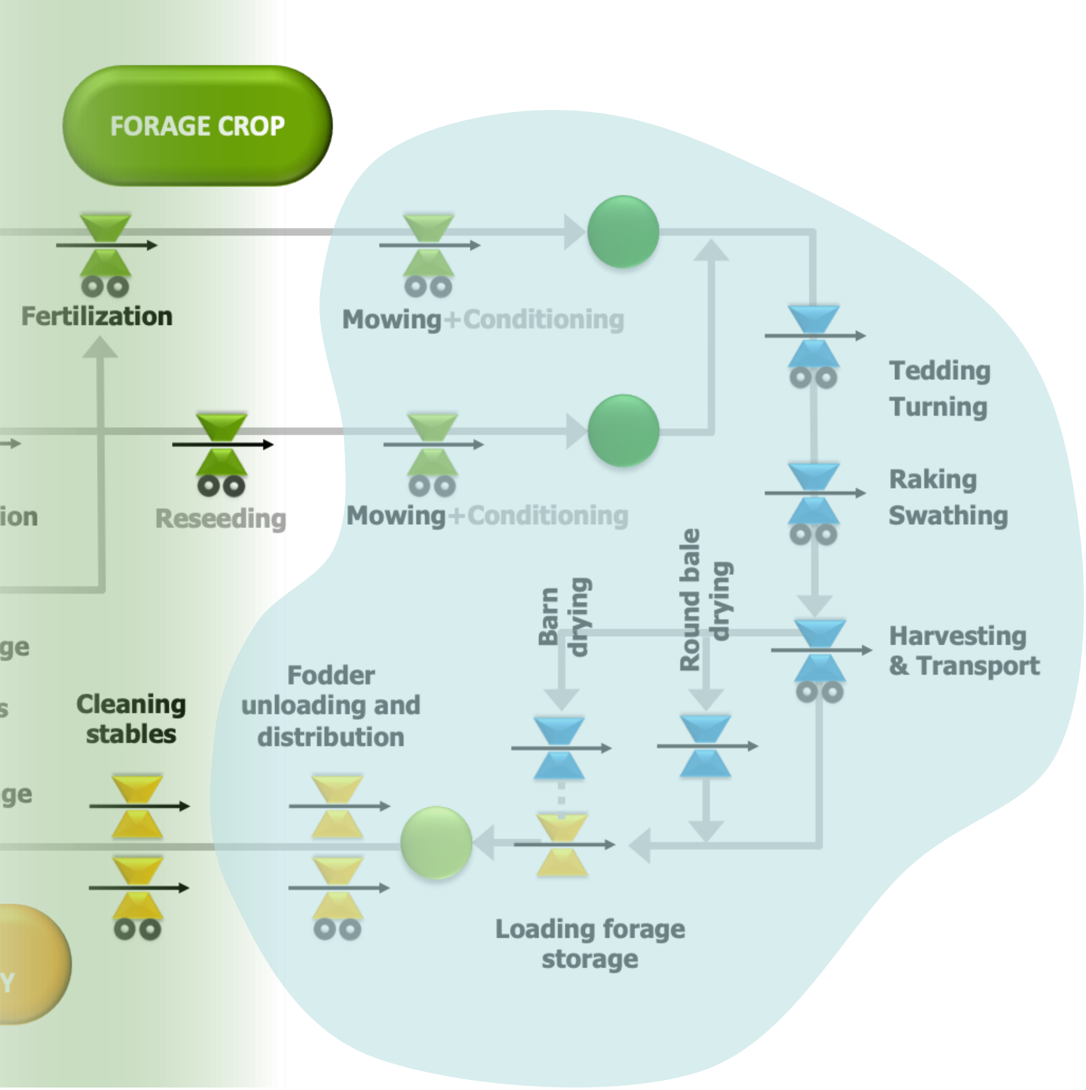
# INTERDISCIPLINARY GAPS



# INTERACTING PROCESSES

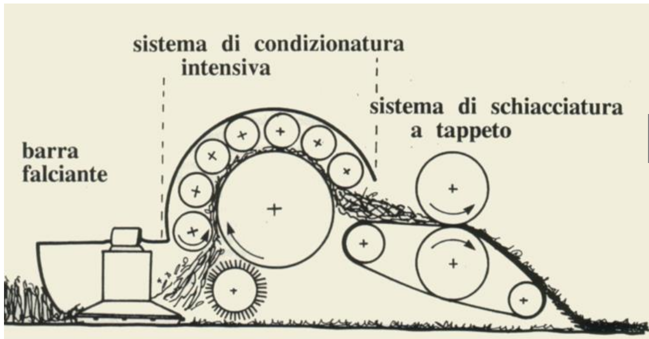


# FORAGE EXTENDED DOMAIN

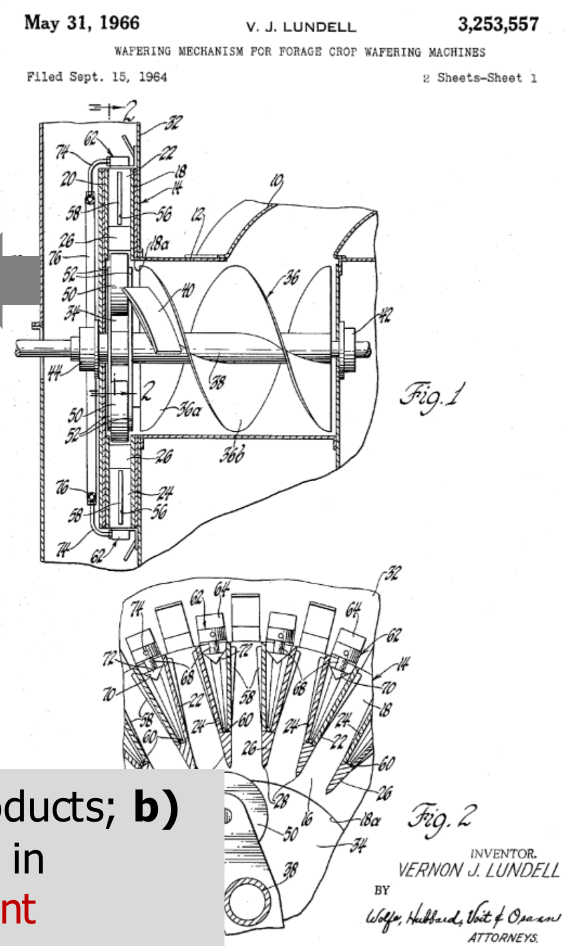



- The way a process is carried out often has **implications** for subsequent processes
- The implications may concern both the **quality of products** (final or intermediate) and the **work organisation**
- Many processes **overlap** between contiguous sectors (e.g. mowing and drying) and can heavily influence the organisation of both
- Difficulties in identifying **radical innovations** (incremental innovations are favoured)

# Some radical proposals then abandoned…

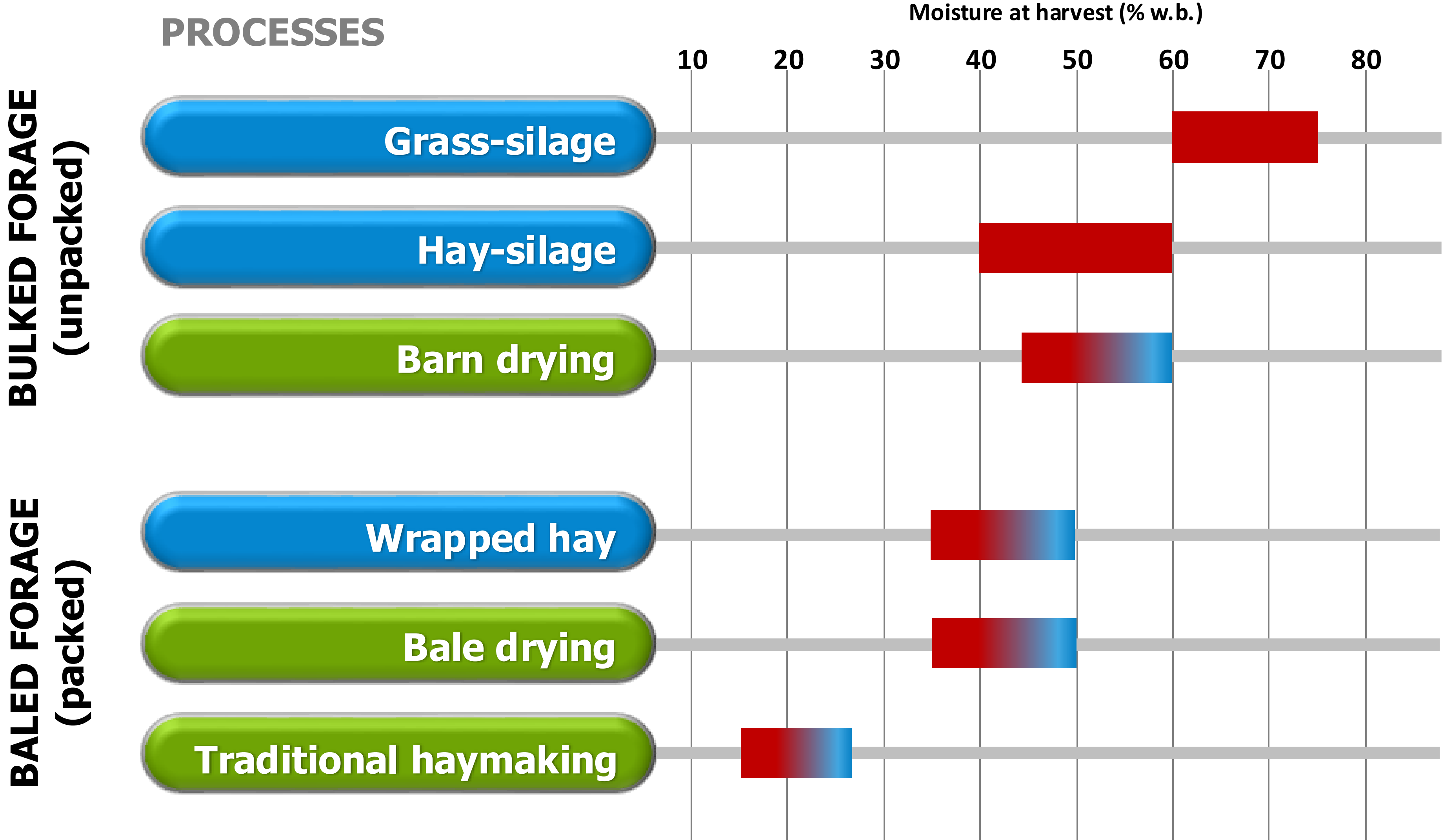



- **SUPERCONDITIONER**: multidrum, squeezing and pressing with dense mat formation to speed up drying in the field
- **WAFERING**: to converting forage into relatively small, high-dense, and uniform blocks called wafers
- **STACKHAND**: to collect large forage masses in one big package to facilitate subsequent transport and storage operations

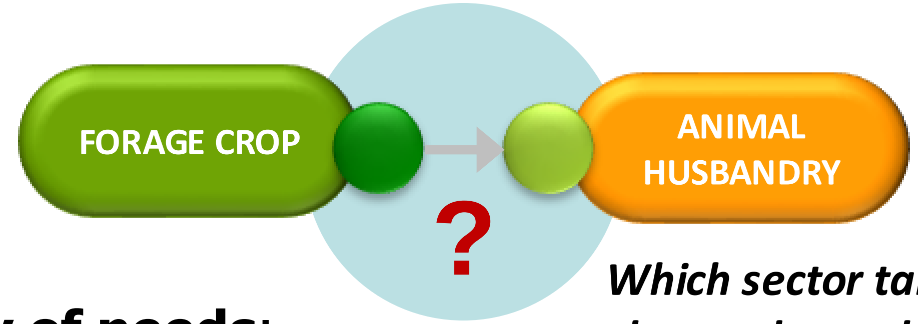




**Problems** due to: **a)** uniformity of products; **b)** quality of nutrient content; **c)** difficulty in handling; **d)** integration with subsequent operations

# STATE OF THE ART



## What priorities?




***Which sector take in charge the problems?***

There is a **high variability of needs**:

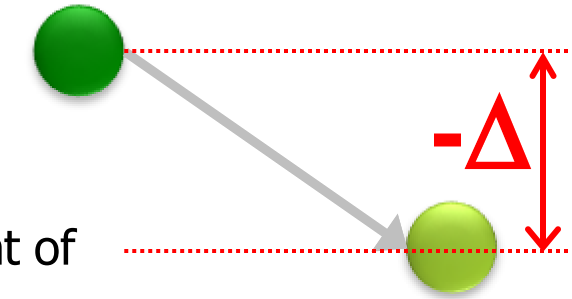
- Preserve **qualitative and quantitative losses** reduction…
- … even acting on single processes **(incremental innovations)**…
- … but keeping attention to preserve an **optimal work organization** enabling work productivity and *reduction of production costs,* even with a high attention to workers´ safety (one-health approaches) and environmental impacts…
- till to promote **advanced process certification** tasks of the performance of the *whole production chain*

## What priorities?


Need to act on a **complete enterprise scale**, **integrating** the *decision-making issues* of all individual sectors

- Current ICT solutions enable easier digital control of processes, favouring the transfer of information **between single sectors** or even directly between individual machines/plants (**M2M**), facilitating operational and management control functions
- Provide automated solutions for field processes, with a focus on **worker safety conditions**, especially in *mountainous areas*
- Both **process & product certifications** are required
- Provide **monitoring tools** (continuous or punctual) for the **quality of intermediate and final products** (focus on moisture, energy, and proteins)

# Quantitative & Qualitative losses




- **Quantitative losses** = decrease of the amount of **dry matter available per ha** (*kg/ha d.m.)*
- **Qualitative losses** = decrease of nutrient content (**crude protein**, $kg_{cp}$/kg d.m.) or **net energy** (*$MJ_{NEL}$/kg d.m.*)
- Also expressible in *fractional* or *percentage* terms, when referred to their respective original values (*fresh forage*)
- **Total quality losses** per hectare (**$KT_{cp}$** and **$KT_{NEL}$**) are a *combination* of both

$$K_{dm} = \frac{\Delta_{dm}}{DM_{fresh}}$$

$$K_{cp} = \frac{\Delta_{cp}}{CP_{fresh}}$$

$$K_{NEL} = \frac{\Delta_{NEL}}{NEL_{fresh}}$$

$$KT_{cp} = K_{dm} + K_{cp} - K_{dm} K_{cp}$$

$$KT_{NEL} = K_{dm} + K_{NEL} - K_{dm} K_{NEL}$$

## Losses causes ($K_{DM}$ % d.m.)

| | |
|---|---|
| Respiration | **1 - 5** |
| Leaching | **4 - 8** |
| Fermentation | **5 - 8** |
| Mechanic treatments (crumbles) | |
| ❖ Cut+Cond. | **1 - 2** |
| ❖ Raking | **1 - 4** |
| ❖ Baling | **3 - 5** |
| TOTAL | **15 - 30** |

***a)*** *Max. values with prolonged rainfall on conditioned forage;* ***b)*** *Max. values in the field with very wet soil conditions:* ***c)*** *Values per single intervention, very high if carried out at moisture < 40% w.b;*

## Example combined losses

**(crude proteins)**

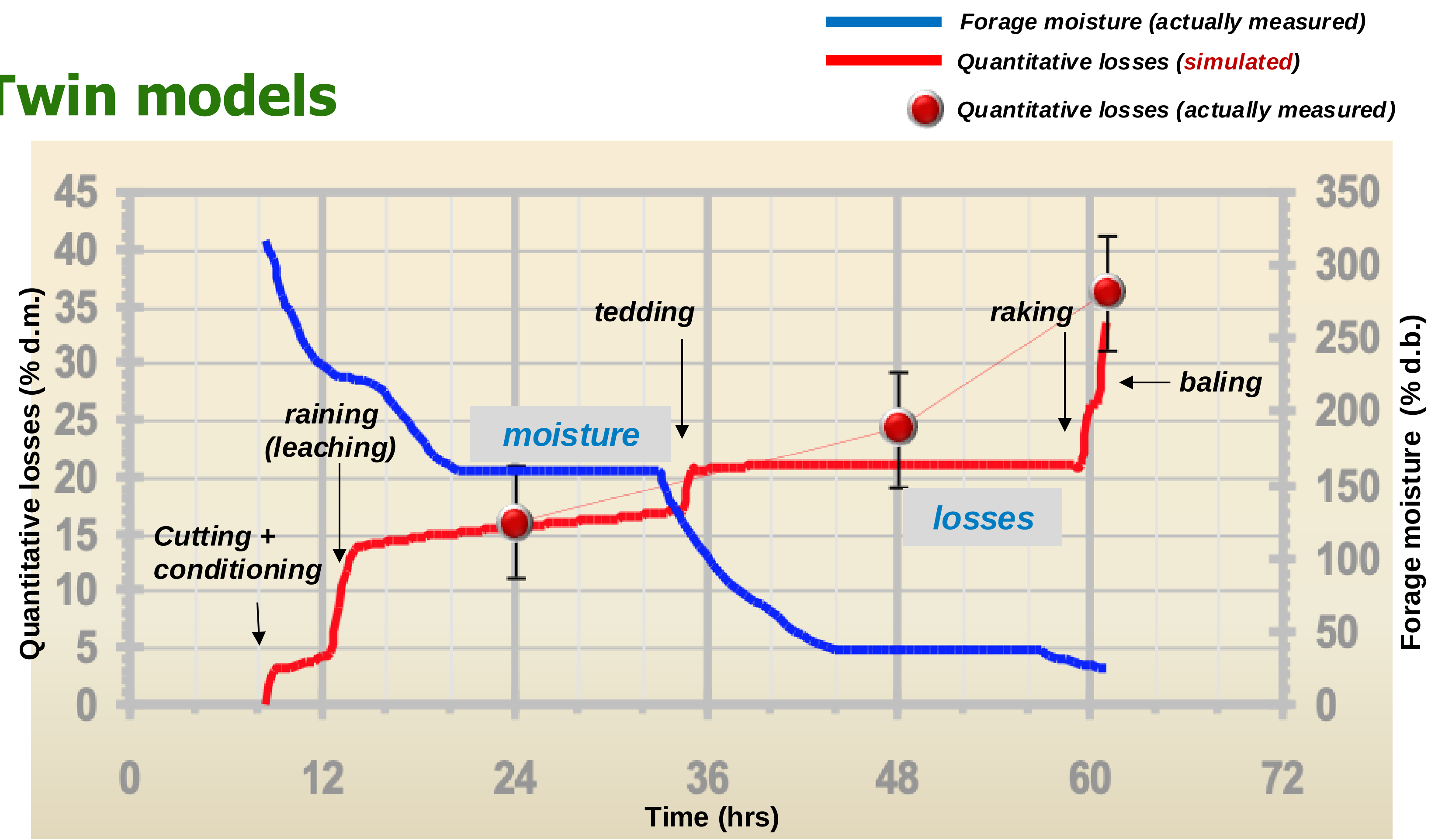
**$DM_{fresh}$ = 5000 $kg_{dm}$/ha** **$CP_{fresh}$ = 0,22 $kg_{cp}/kg_{dm}$**

**$\Delta_{dm}$ = -25%** **$\Delta_{cp}$ = -20%**

**3750 $kg_{dm}$/ha** **0,176 $kg_{cp}/kg_{dm}$**

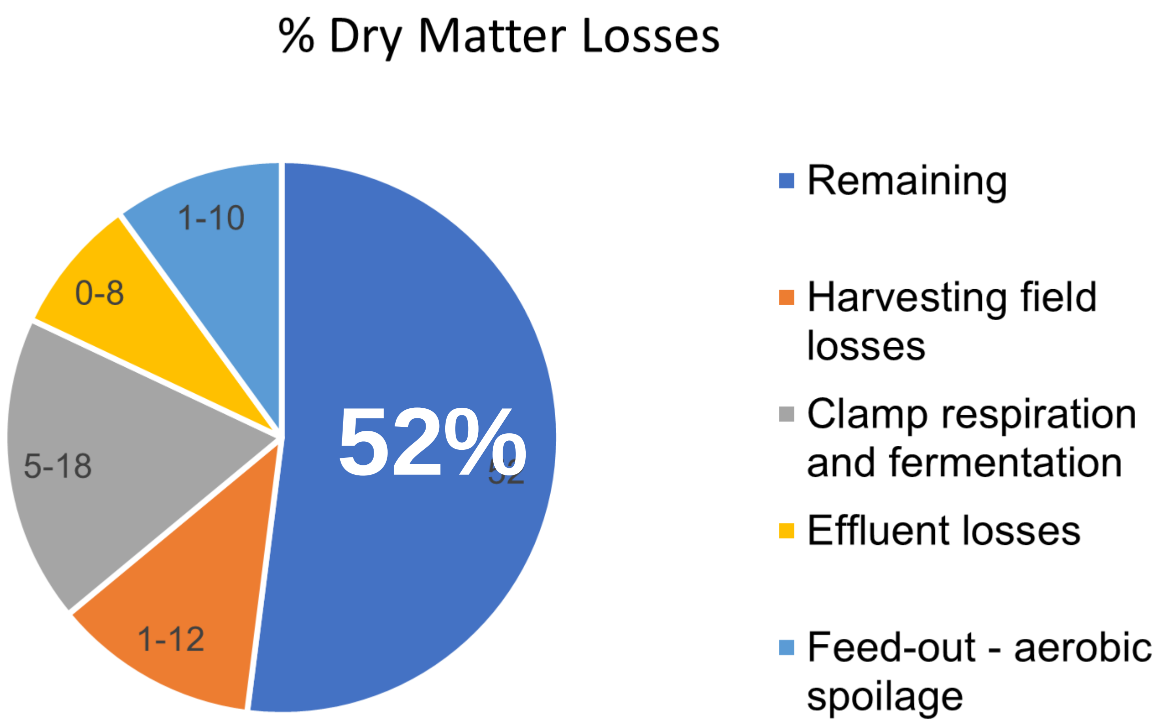
**From 5000 0,22 = 1100 to 3750 0,176 = 660 $kg_{cp}$/ha**
**Tot Losses = 440 $kg_{cp}$/ha ($KT_{cp}$ = 40%)**
***(equivalent to approx 2 t/ha concentrates !!!)***

# Twin models




- Application on conditioned **alfalfa** that has been affected by a rainfall event immediately after cutting

# Documented experience from UK




Source: Institute of Grassland and Environmental Research, UK, 2012

- More less than 50% losses along the entire process chain!

# Losses model for horizontal silage production

Control parameters

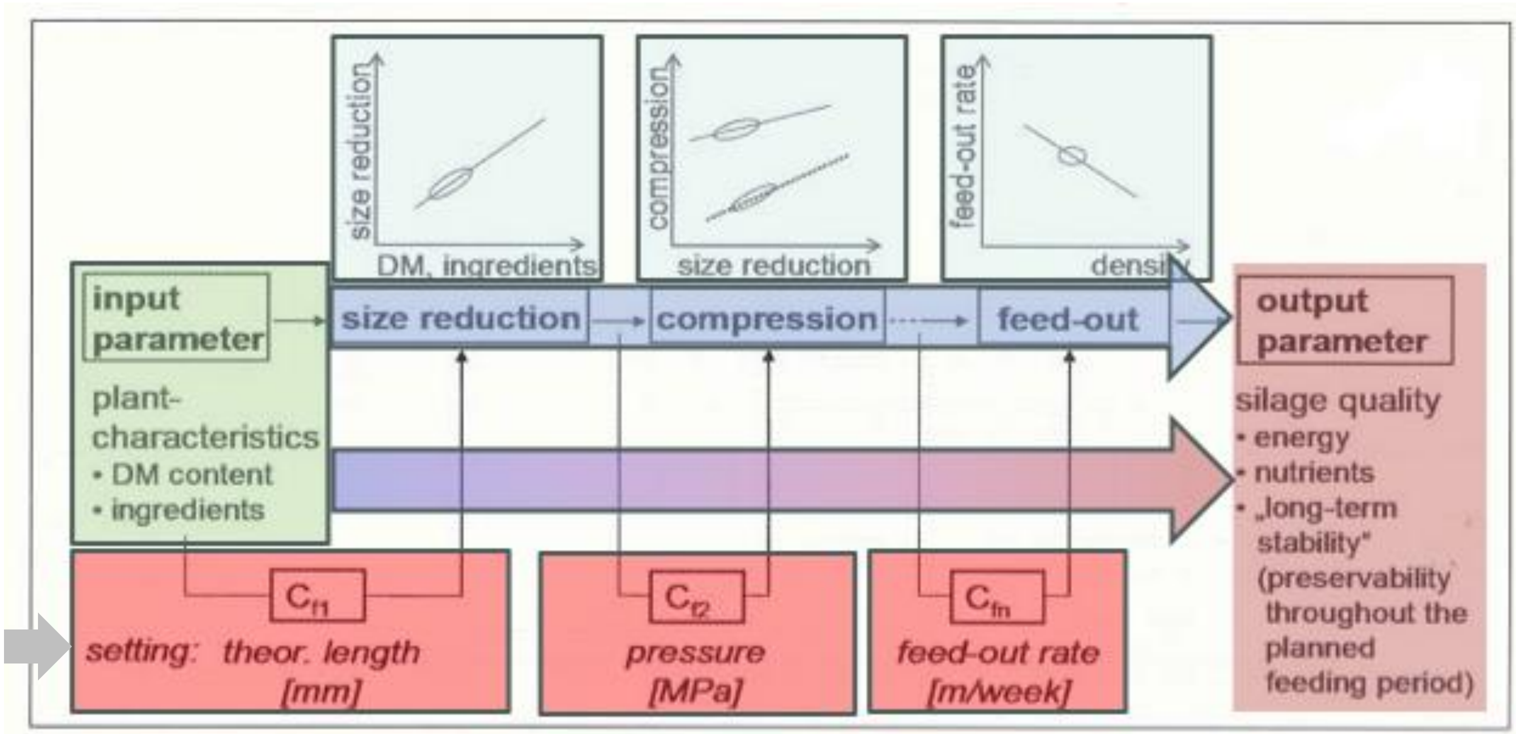
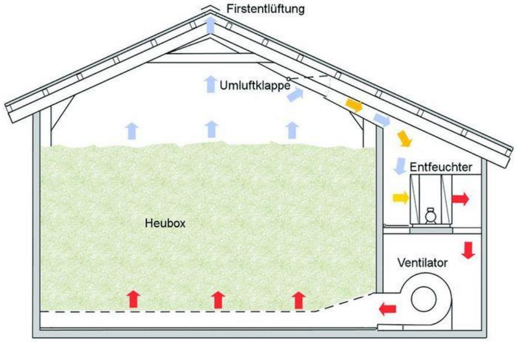


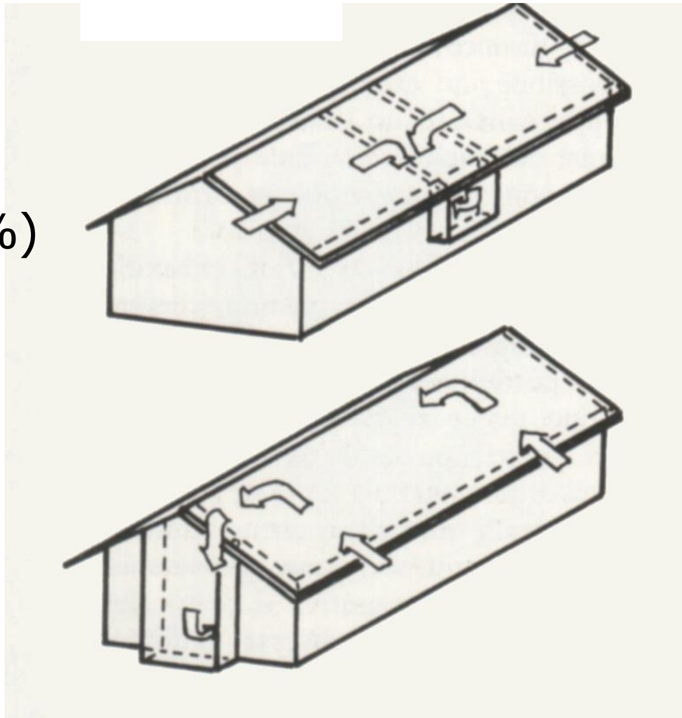

*Fig. 1: Control loop for quality assurance of silage (c = control, f = factor) [1]*

source: Wagner & Pries; Landtechnik 5/2006

- **Size reduction** + **material compression** + **feeding out-rate** from the silo determine the amount of losses
- The parameters could serve for modeling and control values for FMIS

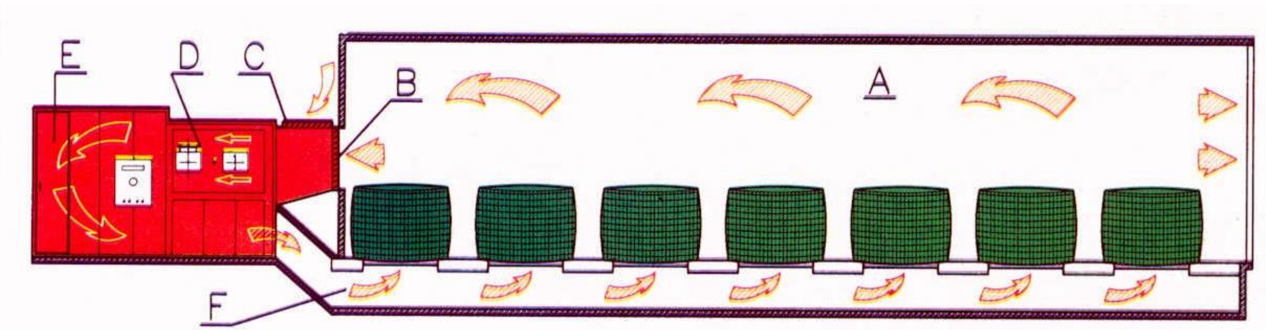


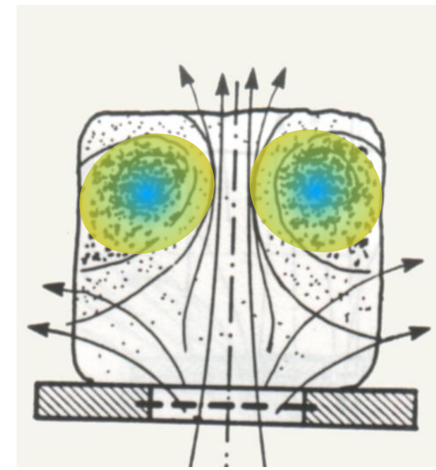

# Two stage drying (solar barn drying)

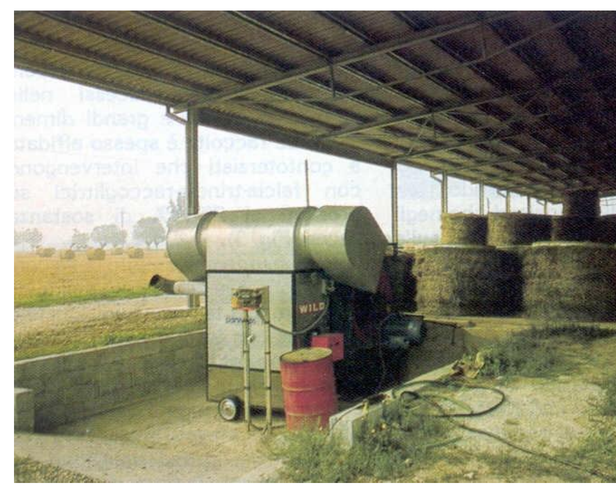


- Relevant **mitigation of losses** ($K_{dm}$ and $K_{cp}$ <<15%)
- **High investments** and relevant **energy consumptions**, justified only integrating **air solar collectors**)
- Perplexities for dealing with **bulked forage**
- Margins to improve the post-harvest mechanization chain

# Round bale drying



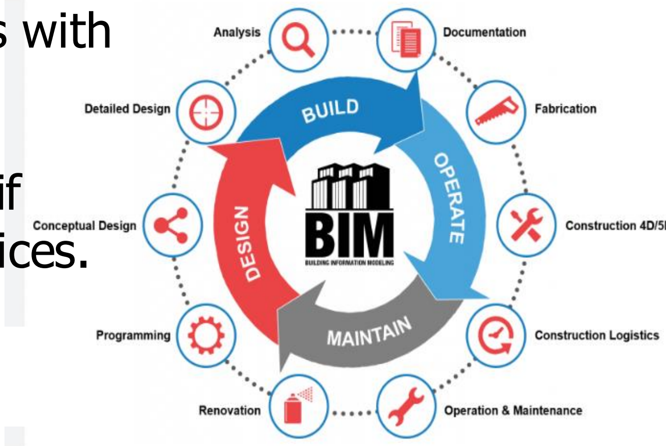





- Moderate **mitigation of losses** ($K_{dm}$ & $K_{cp}$ :15-20%)
- Risks of not homogeneous drying
- **Moderate investments** with sensible **energy consumptions**, (better if integrated with **air solar collectors**)
- Additional post-drying work for storing
- Appreciated for dealing with **baled forage**

# Approaching Building Information Model tools

- **BIM** = Methods for optimising the **planning**, **implementation** and **management** of constructions with the help of IT infrastructures.
- Useful for functional building management, especially if they include distributed **monitoring** and **control** devices.
- **Integration of functional buildings into the FIS**



# Wrapped hay

- Flexible solution enabling the **combination of the production** of both hay and hay-silage at farm, *without any relevant investment* in functional building
- Moderate **mitigation of losses** ($K_{dm}$ & $K_{cp}$ :15-20%), without any drastical change with traditional haymaking with **baled forage**
- Need of a protection structure (**wrongly** bales are often *left in the field*)
- Significant quantities of **plastic** to be disposed

# «Digitalized» large big balers


- **SQUARE** more favourite than **ROUND** bales, due to **transport and storage** advantages
- Progressively equipped with a rich **array of sensors**, for continuously detecting material parameters (weight, moisture, nutrient content…) → **ISOBUS to be connected to the FIS**
- **1)** Regulate **differentiated pressure**; **2)** prevent to work **not suitable material**; **3)** correctly dose **additives**, to improve the quality and shelf life of the forage

# «Smart baling”

- The KRONE SmartBale app (enabled by the “*yellow component*”) allows information on the baled crop

- These include the **location** of the bales, to be easily read out via smartphone, making the work processes involved in hay/ straw harvesting much easier for the related logistic tasks

- Implementing the **traceability** of the bale origin, with related advantages on **diet definition** based on reliable quality information

# Belt rake for swathing

Single axle tractor, drum wheels





Flexible pickup

- Originally developed for mountain harsh terrain, nowadays also for flat lands
- Smooth treatment with lower losses per treatment (< 2%)

# «Heroic Forage Farming”

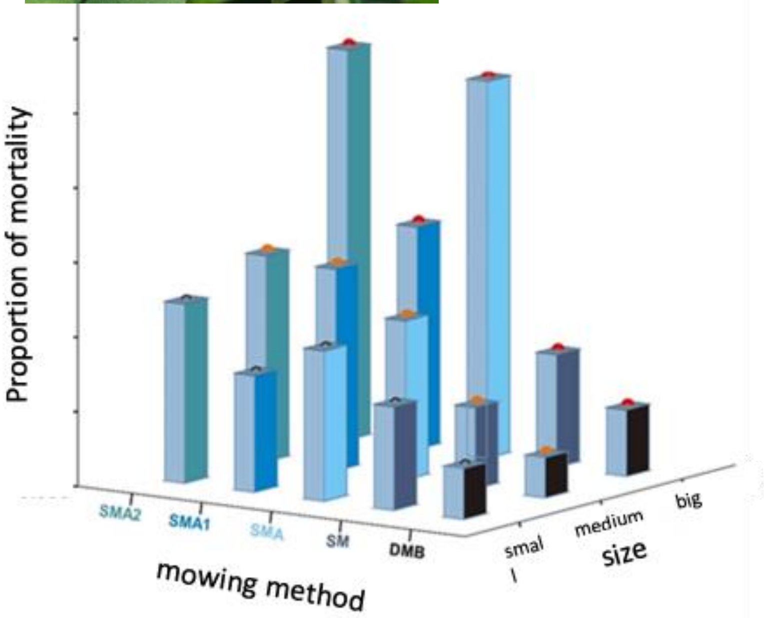
- Haymaking machines specifically developed for **prohibitive** conditions
- **Risks & Social sustainability** of the work should be accurately evaluated




# Solutions for wild animal  protection

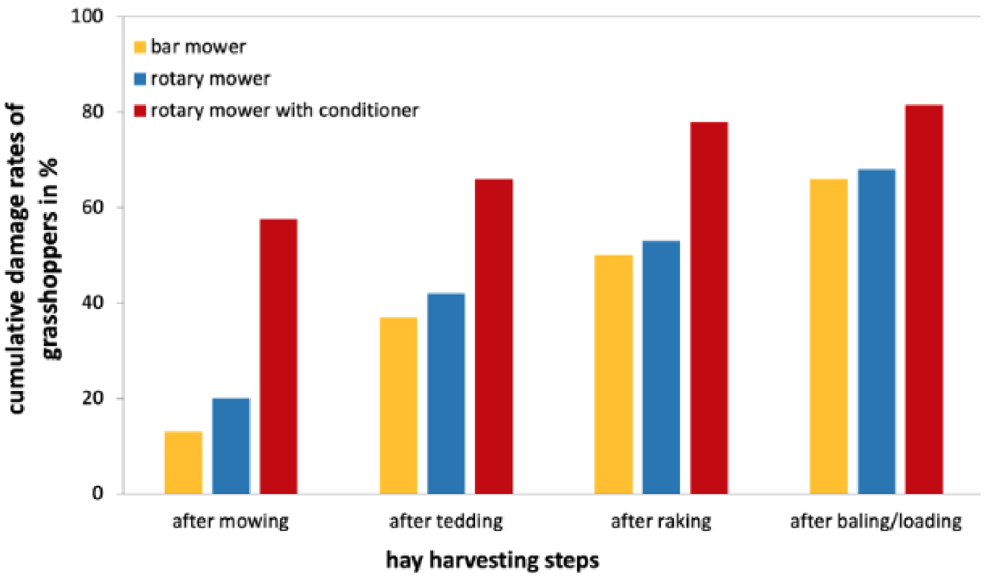

- Harvester can detect the presence of **young deers** among the grass through an array of **optical sensors** mounted on the frontal bar of the machine; once detected, the mower automatically lifts up (hydraulically driven)
- Other solutions apply drone on-board sensors to produce **prediction maps** for manual time-differed actions

# Solutions for insect protection




DMB = double knife mower bar; SM = disc mower; SMA = disc mower with conditioner; SMA1 and SMA 2 = 2 prototypes of insect protectors

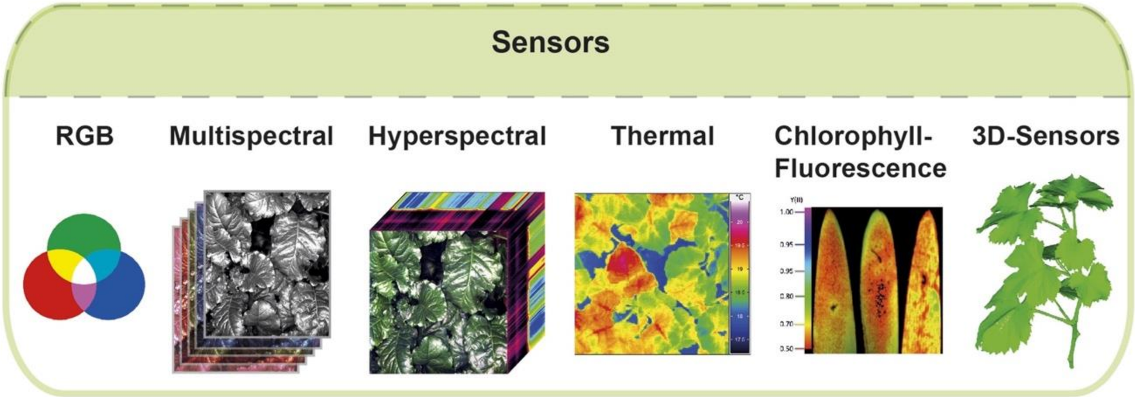
Source: Hintringer, J. et al. 2023




Source: Lea von Berg, Jonas Frank, Manuela Sann, Oliver Betz, Johannes L. M. Steidle, Stefan Böttinger; LANDTECHNIK 78(2), 2023,

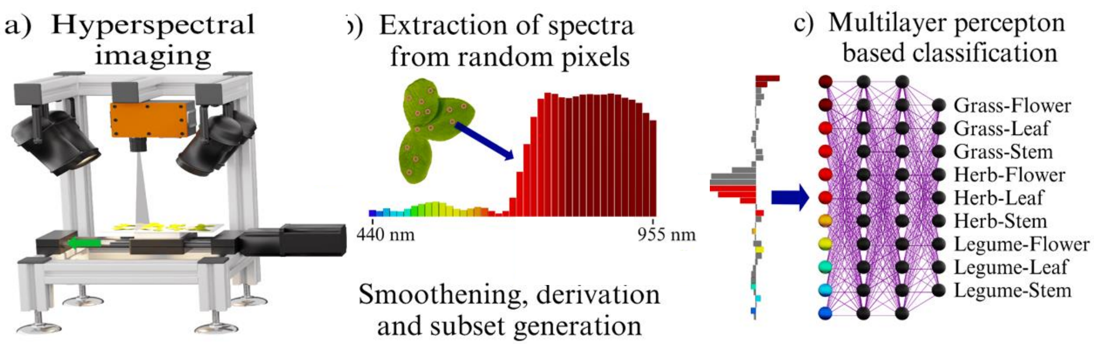
- Clear correlation between the **insect size** and the proportion of dead insects
- Dependence of mortality on the **mowing technology** and **subsequent processes**

# Sensors for grassland quality detection



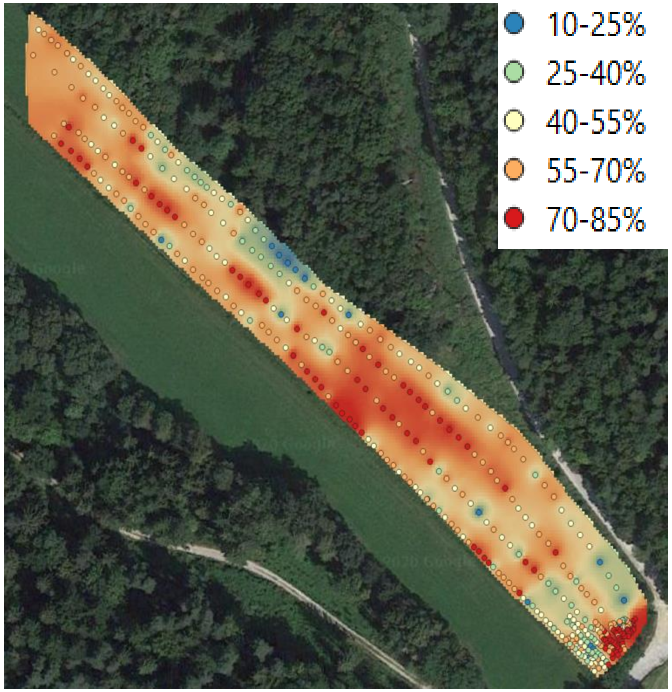

Source: Mahlein, A-K. (2016): http://dx.doi.org/10.1094/PDIS-03-15-0340-FE

## Deep Learning for Computer Vision




- Increasing use of **computer vision technology** to be expected

- **To be applied both to growing plant and fresh product at harvest**




**Grass** distribution map calculated by a neuronal net (source: Gronauer, et al. 2021)

# Robotics for grassland management (1)


- Several robot/automated solutions are already available on the market, mainly to face to problem of **cutting grasslands on steep**, very **prohibitive lands** (→ *focus on safety aspects*)
- Many of them are still working in a remote controlled mode (**teleoperated**), with **TRL = 5..7**
- Actual cutting robots largely available at commercial level (**TRL = 8..9**) are related to **small machines** suitable for *gardening* and/or small **confined environments**

# Robotics for grassland management (2)

Robot rake


Robot baler

- Prototypes for **further operations** (e.g. raking, baling) are still under development at an earlier stage (**TRL<5**)
- The general problem of robot application is anyhow still subjected to **strict regulations**, that *hamper their diffusion in the grassland large open environments*
- Even the **FMIS architecture** must be deeply adjusted to provide the new functions robots require
- A new type of **professional training** will be necessary, as well

# Available for a Smart FORAGE System?

- As far single machinery is concerned, **innovation priorities** should be firstly addressed distinguishing between INTENSIVE vs. EXTENSIVE farming systems, even in relation to the **features of the grassland working environment**
- **INTENSIVE**: fodder production in flat lands, large cultivated area, more relevant use of silages even to enhance work productivity to manage harvesting tasks within very strict times (strict seasonal rotations for forage crops);
- **EXTENSIVE**: forage production in mountain regions, wetlands, pasture,…
- **Common objectivities** to be implemented with different strategies:
  - Increase of **fodder quality** (reduction of losses and contamination)
  - Getting the **optimum cutting time** to high forage quality (through sensors)
  - Periodic **reseeding** using application (*prescriptive, site-specific*) maps
  - Sensor monitoring of critical machine and **implement functions** (e.g. blade sharpness, height settings, processing intensity)
  - Development of **robots** (teleoperated machines) for difficult terrain (**safety targets**)

# Yes, but...

- **Relevant (RADICAL) innovations** must necessarily move into an integrated vision of the animal farming systems, where **all the interconnections** among single sectors (*crop, husbandry, wastes*) are taken into the right consideration

- Regardless the farming system, this approach necessarily requires the **adoption of a FMIS** with **sustainable costs** to enable the right integration of **monitoring** and **controlling** tasks, especially in view of the development of highly sensor-equipped machines

- The FMIS will even have to provide decisional supports to aspects related **worker safety** and **environmental protection**, also in relation to **certification** and **traceability** tasks

- Finally, FMIS must open to the expected evolutions towards large land distributed systems, with an increasing use of robots and (IoT) distributed sensor networks  for wireless (fixed or portable) monitoring tasks…

- … a **radical innovation** then could be the development of **new international standards** to foster the adoption of digital solutions, with analytical functions to be supported by *external services via cloud computing approaches*


very very much
THANK YOU
FOR YOUR
ATTENTION