AUTOMATIC FEEDING SYSTEM: EVALUATION OF ENERGY CONSUMPTION AND LABOUR REQUIREMENT IN NORTH-EAST ITALY DAIRY FARM

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Abstract. Feeding operations in dairy cow farms are of strategic importance for the economy of the farm. In addition to being strictly related to the productivity of the cows, feeding represents one of the greater costs for farms, considering that more than 25 % of labour time is dedicated to this operation. In a context characterized by the need for maintaining high production standards and of decreasing the costs, the adoption of automated systems for the preparation and distribution of the total mixed ration (TMR) can represent a valid solution, especially in specialized farms. Automatic Feeding Systems (AFS) allow for the increase in frequency of feed distribution with a consequent optimization of dry matter ingestion by the animals, and simultaneously, assist with maintaining a higher stability of ruminal pH along with significant advantages in terms of health and production. Furthermore, they provide a reduction of man labour related to preparation of feed, distribution, and to propel the ration closer to the feeding rack. The present research was focused on monitoring of a dairy farm, located in the Veneto region of Italy, during the transition from a conventional feeding system (CFS), represented by a tractor- operated mixing wagon, to an automatic system equipped with stationary feeding hoppers, a mixing unit and distribution wagon operating on rail. The paper reports a comparative analysis of the functionality of the two systems, including energy consumption and man labor, for preparation and distribution of the TMR. Despite the initial capital investment and maintenance, expenditures have not been taken into account in this study, AFS represent an innovative way to reduce the labour requirements and the improve quality and consistency of work when feeding TMR. In particular, labour was reduced from 2.5 $h \cdot day^{-1}$ related to the CFS to 1.02 $h \cdot day^{-1}$ needed for the management of the AFS. The AFS also demonstrated, to be of interest, with regard to an economic point of view, reducing the costs for preparation and distribution of the TMR. The CFS, in fact, showed a cost of 1.44 $EUR \cdot m^{-3}$ and 0.16 $EUR \cdot cow^{-1}$ per day, and the consumption of energy of 24.66 $kWh \cdot m^{-3}$ and 2.74 $kWh \cdot cow^{-1}$ per day, while the AFS revealed a cost of 0.91 $EUR \cdot m^{-3}$ of TMR and 0.10 $EUR \cdot cow^{-1}$ per day, and the specific energy consumption of 6.81 $kWh \cdot m^{-3}$ of TMR and 0.76 $kWh \cdot cow^{-1}$ per day.

Keywords: dairy cattle, automatic feeding, energy consumption, labour requirement.

Introduction

Feeding operations in dairy cow farms are of strategic importance for the economy of the farm. Aside from being strictly related to the productivity of the cows, feeding represents one of the greater costs for farms, considering that more than 25 % of labour time is dedicated to this operation [1].

Dairy farmers are increasingly evolving toward automation of their farms [2; 3]: automatic concentrate dispensers and automatic milking systems (AMS) have been utilized for years, and several manufacturers have introduced automatic feeding systems (AFS) during the past decade [4; 5].

The main advantage of AFS is the possibility to supply a total mixed ration (TMR) with a high frequency and a low labour requirement, whilst farms that feed with conventional feeding systems (CFS) commonly supply TMR only once or twice a day and require more labour with a rigid work schedule. AFS allows for increasing the frequency of feed distribution, with a consequent optimization of dry matter ingestion by the animals, and concurrently assist to maintain a higher stability of ruminal pH with significant advantages in terms of health and production [6]. Furthermore, a higher frequency reduces the permanence time of feed on the manger with reduced possibility of contamination and of anomalous fermentations [7].

Many researchers have studied the consequences of the feeding frequency [8; 9]. Supplying roughage once or twice a day results in a feeding pattern that is characterized by daily peaks of visits to the feeding fence immediately after the feed delivery. However, increasing the feeding frequency stimulates the visits to the feeding fence and leads to a more evenly distributed visiting/feeding pattern.

The shift to an automated TMR feeding system requires expensive investments, even if a fairly wide range of models different in complexity and cost became to be available on the market. On the other hand, robots seem to require less space and power than a standard tractor-pulled mixer wagon [10; 11].

For these reasons, the present research was focused on the monitoring of a dairy farm, located in the Veneto Region of Italy, with a herd of 90 lactating cows, during the transition from the conventional feeding systems (CFS), represented by a tractor-operated mixing wagon, to the automatic feeding systems (AFS) equipped with stationary feeding hoppers, a mixing unit and distribution wagon operating on rail. The paper reports a comparative analysis of the functionality of the two systems, including the energy consumption and man-labor for preparation and distribution of the TMR.

Materials and methods

Dairy farm and TMR composition

The study was carried out on a private dairy farm located near Treviso in Northeast Italy. The farm was characterized by a free-stall system, housing 90 lactating cows, with concrete floor and surface scrapers for a frequent removal of manure. Installed in the center of the housing there is a single AMS, single box type (SAC, Denmark). The average milk production resulted in 8 435 kg·cow^{-1} per year. The prevailing breed was Holstein-Friesian.

The cows were supplied with the diet described in Table 1. The ration, in particular, is composed of cereal silage (51.0 % DM), maize flour and cottonseed (24.3 % DM), concentrate (13.2 % DM), and hay (11.5 % DM). Each animal was fed, on daily basis, with 12.2 kg of cereal silage, 5.7 kg of maize flour and cottonseed, 3.1 kg of concentrate, and 2.7 kg of hay. While concentrate was supplied by the automatic dispenser in the AMS, the remaining components are mixed to obtain a Total Mixed Ration (TMR). After mixing of the components, the TMR presented a volumic mass of 245 kg·m^{-3}, with a dry matter (DM) content of 50 %.

Table 1

TMR composition and feed intake

Fodder	Ration composition (% DM)	Feed intake (kg·cow^{-1}·day^{-1})
Cereal silage	51.0	12.2
Maize flour and cottonseed	24.3	5.7
Concentrate	13.2	3.1
Hay	11.5	2.7
Total	**100**	**23.7**

Feeding Systems

In the initial configuration, the farm adopted traditional equipment for preparation of the TMR. The conventional feeding system (CFS), in particular, featured a TMR feeding unit represented by a 10 m^3 nominal volume trailed mixer wagon equipped with a single, vertical axis auger (Fig. 1). A 4WD, 80 kW (Same Deutz-Fahr mod. Explorer, Italy) nominal power tractor was dedicated to operate the wagon. A telescopic handler machine (73 kW) (Manitou mod. MVT, France) was used for loading the mixer with the components of the ration. Maize silage was stored in a horizontal silo with concrete walls and plastic film cover; baled hay and grains were stored in a dedicated storage structure, while concentrates were stored in two different vertical silos.

In the first configuration, the distribution of the TMR was performed once a day (at 7:00 a.m.)

The automatic feeding systems (AFS), installed in a second time and considered for the comparison (DeLaval Optimat Master, manufactured by DeLaval International AB, Tumba, Sweden), featured a self-loading device with 3 feed-stations and a self-propelled chopping-mixing-feeding unit 10 m^3 nominal volume, equipped with n. 2 vertical augers. The distribution was performed by a dedicated wagon loaded by feed conveyor belt: this unit, characterized by a nominal volume of 3 m^3, was suspended on an overhead rail and maneuvered independently along the track (Fig. 2). The whole system was powered by electric motors and offered the possibility of varying the ration several times per day according to the requirements of the dairy farm.

In both configurations the TMR ratio was 10 m^3·day^{-1}.

Fig. 1. **Conventional feeding system (CFS) represented by a trailed mixer wagon, equipped with a single, vertical axis auger**

Fig. 2. **Components of the AFS: the TMR mixing unit, the feeding hoppers (left) and the distribution wagon (right)**

Operating parameters

The research was conducted with the main objective of comparing the two systems in terms of performance and requirements of energy and labour. Three monitoring campaigns were performed for each system. The parameters subject to investigation were represented by:

- effective working time ($h \cdot day^{-1}$) for each TMR phase (loading, mixing and distribution);
- diesel fuel consumption for each working phase ($kg \cdot day^{-1}$);
- daily energy consumption ($kWh \cdot day^{-1}$) for each motor;
- man-labor ($h \cdot day^{-1}$) needed for the TMR phases (loading, mixing, and ration management).

The determination of energy consumption was performed in various ways according to the type of motor-diesel or electric. For diesel motors, fuel consumption was determined by filling the tank before and after each phase. The cost related to fuel consumption was determined considering the cost for Diesel of 0.765 $EUR \cdot kg^{-1}$. To achieve a comparison of energy demand of the two systems (in kWh), Diesel consumption was transformed by considering the energy content of this fuel, equivalent to 47.3 $MJ \cdot kg^{-1}$. Energy consumption of electric motors was simply determined by multiplying the installed power and operation time. The cost related to the operation of electric motors was determined by considering 0.18 $EUR \cdot kWh^{-1}$ for electric energy.

For the CFS, the study was initialized approximately 3 months before and after the AFS was installed in the farm.

Results and discussion

Feeding systems operating performances

The first phase was represented by the *feed ration management*, intended as collection of the component from the storage facilities and conveying to the TMR preparation unit.

For the CFS, however, this phase is intended as direct loading of the mixing unit, for the AFS, instead, it is intended as loading of the hoppers that operate as the automated loading system of the stationary mixing unit. For both CFS and AFS, this phase was performed by Telehandler (Tables 2 and 3).

This phase was performed once a day, but the operation time varied between the two feeding systems: for the CFS 0.98 h·day^{-1} was required, while for the AFS, the required time resulted in 0.27 h·day^{-1}. This difference was related to the fact that the components of the TMR are conveyed to the loading system of the AFS once every three days.

The cost of this operation resulted in 5.47 EUR·day^{-1} for the CFS and of 1.53 EUR·day^{-1} for the AFS. As mentioned, the loading of the AFS mixing unit requires additional steps, represented by the operation of the feeding hoppers that discharge the different components on the conveyor belts. The loading of the mixer requires 1.59 h·day^{-1}, with a consumption of 4.66 kWh·day^{-1} of electric energy and a cost of 0.85 EUR·day^{-1} (Table 3).

Once loaded in the wagon, the components of the ration were subjected to *cutting and mixing*. In both systems, this operation was performed once a day. In the CFS, this operation endured for 0.67 hours, while in the AFS the required time was 1.00 hour according to Penn State Particle Size distribution of feeds [12]. The CFS mixing unit determined a consumption of 9.97 kg·day^{-1} of Diesel, equivalent to 104.76 kWh·day^{-1} and with a cost of 6.10 EUR·day^{-1}; the mixing phase of the AFS determined a consumption of 30 kWh·day^{-1} with a cost of 5.44 EUR·day^{-1} for electric energy.

The *distribution* of the TMR by CFS was performed once a day in 0.45 hours. This phase includes operation of the mixing screw and of the conveyor belt used for discharging the TMR. The fuel consumption resulted of 3.65 kg·day^{-1}, with a corresponding energy demand of 47.89 kWh·day^{-1} and a cost of 2.79 EUR·day^{-1} (Table 2).

For the AFS this phase was performed four times a day. The operations included activation of the mixing wagon prior to the discharge, the discharge and the loading of the distribution wagon, and operation of the wagon itself (Table 3). The comprehensive time required by the 4 distributions was 1.65 h·day^{-1}, with a consumption of 7.12 kWh·day^{-1} and a cost of 1.29 EUR·day^{-1}.

In general, the requirement of labour related to the CFS results in 2.5 h·day^{-1}, significantly higher than the 1.02 h·day^{-1} needed for the management of the AFS (Fig. 3). The aforementioned includes only the loading by telehandler and labour/control, essentially related to the program of the AFS; the operation time of the AFS itself was not included in labour time considering the automated operation of the system. In terms of energy, the CFS determined a consumption equivalent to 246.64 kWh·day^{-1}, significantly higher than the 68.05 kWh·day^{-1} required by the AFS. Diesel powered phases were determined to be the most energy demanding; the phase that requires more energy for both systems, in general, is represented by mixing, followed by loading of components (Fig. 3).

Table 2

Performance of the conventional feeding systems (CFS)

Operating phases, h·day^{-1}	**No. of operations per day**	**Time h·day^{-1}**	**No. of motors**	**Power, kW**	**Fuel consumption, kg·day^{-1}**	**Energy consumption, kWh·day^{-1}**	**Cost, EUR·day^{-1}**
Loading of TMR components (Telehandler)	1	0.98	1	73	7.15	94.00 **	5.47 *
Cutting and Mixing (Tractor PTO on)	1	0.67	1	80	7.97	104.76 **	6.10 *
Transportation (Tractor PTO off)	1	0.45	1	80	3.65	47.89 **	2.79 *
Logistic/conveyor and distribution	1	0.40	-				
TOTAL		**2.5**			**18.77**	**246.64 ****	**14.36 ***

*Considering a Diesel cost of 0.765 EUR·kg^{-1}

** Considering an energy content of 47.3 MJ·kg^{-1} for diesel fuel

Table 3

Performance of the automatic feeding systems (AFS)

Operating phases, h·day^{-1}	No. of operations per day	Time h·day^{-1}	No. of motors	Power, kW	Fuel consumption, kg·day^{-1}	Energy consumption, kWh·day^{-1}	Cost, EUR·day^{-1}
Loading TMR components							
Hay	0.33	0.05	1	73	0,39	5.06 **	0.29 *
Baled	0.33	0.05	1	73	0.36	4.75 **	0.28 *
Silage	0.33	0.13	1	73	0.94	12.34 **	0.72 *
Flour	0.33	0.04	1	73	0.31	4.11 **	0.24 *
		0.27			**2.00**	**26.27 ****	**1.53 ***
Labour/control	1	**0.75**	-				
Loading hopper							
Hay hopper	1	0.20	2	2.2	-	0.88	0.16 ***
Baled hopper	1	0.23	2	2.2	-	1.01	0.18 ***
Silage hopper	1	0.10	2	2.2	-	0.44	0.08 ***
Conveyor belt	1	0.53	1	2.2	-	1.17	0.21 ***
Elevator belt	1	0.53	1	2.2	-	1.17	0.21 ***
		1.59				**4.66**	**0.85 *****
Cutting/Mixing	1	**1.00**	1	30.0	-	**30.0**	**5.44 *****
Distribution							
Pre-distribution Mixing	3 ****	0.45	1	8	-	3.6	0.65 ***
Wagon loading	4	0.32	1	2.2	-	0.7	0.13 ***
Distribution wagon	4	0.44	4	0.6	-	1.06	0.19 ***
	4	0.44	1	4		1.76	0.32 ***
		1.65				**7.12**	**1.29 *****
TOTAL						**68.05**	**9.11**
Man labour		**1.02**					

* Considering a Diesel cost of 0.765 EUR·kg^{-1}

** Considering an energy content of 47.3 MJ·kg^{-1} for diesel fuel

*** Considering 0.18 EUR/kWh^{-1} for electric energy

**** The first Mixing pre-distribution is included in the mixing time

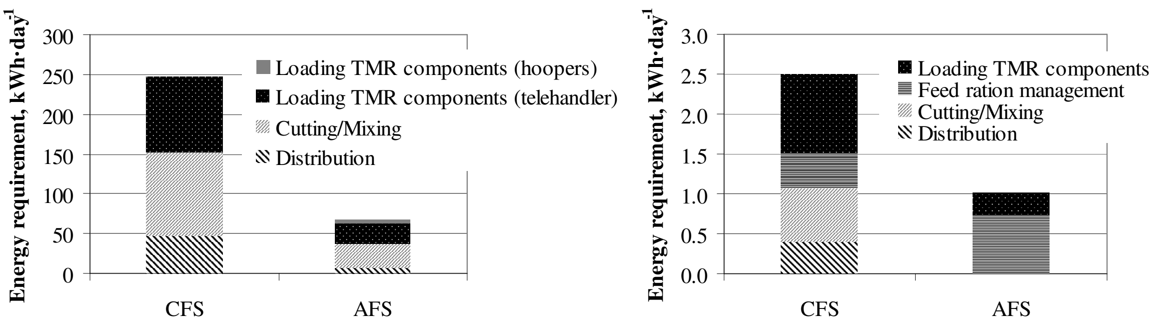

Fig. 3. **Energy consumption and labour requirement for the different phases of preparation/distribution of the TMS in the CFS and AFS systems**

Conclusions

The paper reports a comparative analysis of the functionality of the two systems, including energy consumption and man-labor, for preparation and distribution of the TMR in a Northeastern Italy dairy farm.

AFS could represent an innovative way to reduce the labour requirements and improve the quality and consistency of job performance when feeding TMR.

In particular, labour was reduced from 2.5 h·day^{-1} related to the CFS to 1.02 h·day^{-1} needed for the management of the AFS. The AFS also demonstrated, to be of interest, with regard to an economic point of view, reducing the costs for preparation and distribution of the TMR. The CFS, in fact, showed a cost of 1.44 EUR·m^{-3} and 0.16 EUR·cow^{-1} per day, and a consumption of energy of 24.66 kWh·m^{-3} and 2.74 kWh·cow^{-1} per day, while the AFS revealed a cost of 0.91 EUR·m^{-3} of TMR and 0.10 EUR·cow^{-1} per day, and a specific energy consumption of 6.81 kWh·m^{-3} of TMR and 0.76 kWh·cow^{-1} per day.

Further aspects to be investigated are the effect in terms of the quality of the TMR, the impact of the new system on the behavior of animals, and on the performance of the herd. A primary significant advantage is represented by the increase of the number of distributions, from 1 to 4 per day, with potential advantages in terms of animal welfare, thereby reducing the competition for food.

An additional advantage could be represented by the possibility of powering the AFS with electric energy produced by renewable sources, such as CHP from biogas or photovoltaic panels.

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