Parametric analysis of the properties of selected mixing feeding wagons

J. Vegricht, P. Miláček, P. Ambrož, A. Machálek

Research Institute of Agricultural Engineering, Prague-Ruzyně, Czech Republic

Abstract: Eight different mixing feeding wagons (MFW) were investigated under identical conditions in preparing total mixed rations (TMR) for three various cattle categories. Investigated were the uniformity of distribution of the feed into the trough, homogeneity of TMR distributed, the machine capacity in feed extracting from storage and loading, TMR mixing and distributing into the trough, fuel consumption and power consumption required. The least uniformity was found for TMR with a high hay proportion (average value of standard deviation 49.9%). Better results were achieved with MFW designed with horizontal mixing augers (average standard deviation 33.7%). MFW with vertical augers distributed feeds at average standard deviation of 61.3%. Standard deviation of the proportion of feed particles on the separator screens which is considered as a measure of TMR homogeneity, was bellow 20% in most cases. This suggests a hint of a very good mixing efficiency of all the MFW followed up. No influence of different designs of the working elements of MFW on TMR homogeneity has been proved. With respect to the machine capacity (output) in preparing and distributing TMR, no large differences between various MFW were found and their output averaged from all measurements varied within the range of 4.79–5.48 t/h. The least average specific consumption of fuel for preparing and distributing TMR was found in the MFW equipped with vertical mixing augers (1.10–1.11 l/t). MFW with one horizontally mounted mixing auger showed a rather higher fuel consumption (1.30–1.43 l/t). The highest fuel consumption was found with MFW equipped with two parallely mounted mixing augers (1.59–1.63 l/t).

Keywords: mixing feeding wagons; cattle feeding; total mixed rations; output; fuel consumption

The basic feeding technique in cattle and especially in milk cow keeping is the mixed feeding ration prepared of a mixture of various bulky feeds and concentrates often termed as TMR (total mixed ration). The feed ration resulting from such preparation influences favourably the feed reception by animals, their efficiency and state of health (Kudrna 2004). In the past, TMR were prepared on farm stationary mixing plants. They, however, were substituted by mixing feeding wagons (MFW) after 1990. Currently, these are the dominant equipment for TMR preparation and distribution on cattle farms. For example they account for preparing and distributing TMR to more than 80% milk cows in the Czech Republic (Vegricht *et al.* 2006).

The quality of TMR preparation and distribution depends decisively on the quality of mixing feeding wagons and on a suitable design of their working elements while a great influence is also attributed to the correct operation of MFW. A great part of MFW is equipped with the equipment for extracting and unloading feeds stored in trough silos (rotary cutters, cutting shields or frames with active or passive knives) and their loading. Generally, it would be admitted that rottary cutters could injure the structure of the unloaded feeds and have higher power requirements. The mixing of feed loaded in the box of the MFW is most frequently performed by augers with horizontally or vertically oriented rotation axis. Other solutions also exist (mixing shaft shouldered off with paddle elements, expeller blower combined with chain conveyor, rotary drum). MFW with vertical augers have been rapidly expanding especially during the recent period. They are favoured for their less damaging impact on the feeds and sometimes also for their lower power requirements.

Among the most important parameters deciding of the economic efficiency of MFW operation belong the machine capacity (output) of TMR preparation and the fuel consumption. Professional literature offers a lot of general information on the properties of various types of mixing feeding wagons but

Supported by the Ministry of Agriculture of the Czech Republic, Project No. MZE 0002703101.

specific data ascertained by objective measurements under comparable field conditions are missing. Several mixing feeding wagons were tested in the DLG and this association published tests of 19 MFW on its internet pages (DLG 2006). These tests evaluated several parameters (output, power demands, uniformity of feed distribution, etc.). The capacity of the feed extraction and loading varied in the dependence on the feed types within rather wide limits (16.8–133.8 t/h). Similarly, also maximum power demands of extracting and loading feeds varied in a wide range (38–74 kW). Missing, however, are objective evaluations of TMR homogeneity and fuel consumption while just these parameters present themselves as decisive for many farmers standing before the choice of a MFW.

The following parameters are evaluated with respect to the quality of TMR preparation: uniformity of the feed distribution in the trough, homogenity of the feed mixture, and the impact on structural fibre. Besides the correct composition of the feeding ration, a good mixing of all parts of the feeding ration is important to prevent big differences in the nutrient content in the feed distributed on different places of the trough. In the TMR preparation and distribution the feed structure should not be injured as it is important for the digestion and utilisation of the nutrients contained in the feed. In the Czech Republic much interest for evaluating TMR structure and homogeneity was gained recently by the screen separator following the American nutritionalist Robert Van Saun (Adamová 2004). His method can be also utilised for the evaluation of MFW work quality.

The present paper is aimed at measuring and evaluating the basic parameters of selected mixing feeding wagons and their comparison with respect to the influence of their operation and of the technical solution of their working elements on the parameters evaluated.

MATERIAL AND METHODS

Basic properties and operational parameters were measured in total on 9 different mixing feeding wagons. Their basic technical specification and solution of the working elements are resumed in Table 1.

Within the field measurements performed, the following parameters and features were studied and measured of the MFW under evaluation:

– Uniformity of the feed distribution into the trough
– Homogenity of the total mixed ration (TMR)
– Time recording of the TMR preparation and distribution in the cases of heifer rearing, bull fattening, and dry cows
– Machine capacity in feed extraction and loading, TMR mixing and distributing into the trough
– Fuel consumption in individual working operations and the total consumption

Each MFW distributed three different feeding rations calculated for dry cows, bull fattening, and heifer rearing. The compositions of the feeding rations for an average number of 72 dry cows, 200 heifers, and 180 bulls are resumed in Table 2.

Short chopped silages and haylages were harvested with a forage harvester. Meadow hay was harvested with self-loading wagon harvester.

The uniformity of the feed distribution by MFW into the trough was ascertained by weighing the quantity of feed distributed into the trough corresponding to one feeding. This purpose was accomplished by setting trays sized 750 × 800 mm in regular intervals on the bottom of the trough. Subsequently, these were weighed together with the distributed feed. Altogether 10 trays were used

Table 1. Basic technical parameters and design of working elements of mixing feeding wagons followed up

Parameter	Feeding wagon No.							
	1	2	3	4	5	6	7	8
Mixing element	1 vertical auger	2 vertical augers	1 horizontal auger with knives + short auxiliary auger		1 horizontal auger with knives	1 horizontal auger with knives + 2 short auxiliary augers	2 horizontal augers	
Extraction of feed	cutting frame with active knives		rotary cutter					
Box volume (m^3)	9	12	12	12	10	9	11	15
MFW drive	Semi-trailer with CASE MXU 115 tractor							selfpropelled

in each case. The values acquired were treated both graphically and statistically.

When distributing feed into the trough to dry cows and fattened bulls, the tractorist (the same worker for all MFW) only set the initial size of the unloading hole and the constant speed of the tractor – wagon set. He did not intervene otherwise in the TMR loading and distributing process.

When unloading and distributing TMR for heifers, an experiment was performed with the aim to ascertain the uniformity of unloading the feed from storage by means of mixing feeding wagon under identical conditions for all MFW with the exclusion of the influence of the operator. The feeding ration was thoroughly mixed (mixing time about 15 min). The mixing feeding wagon distributed TMR on the floor of an empty trough silo and worked in the following mode:

– Running when distributing at a uniform speed of 1.5 km/h
– Tractor engine speed 1500 rpm
– Opening of the emptying hole of the MFW to 2/3
– Tractorist did not intervene in the TMR unloading process
– Altogether 10 trays were laid in each trough silo in intervals of 3 m
– Total length of the feed layer distributed equalled 30 m

When measuring the machine capacity in feed extracting from storage, loading, mixing, and distributing into the trough, the defined feeding ration was loaded into the mixing feeding wagon with the precision allowed by the possibilities of the loading equipment, and by the experience and skill of the operator. The actual mass of the loaded components of the feeding ration was ascertained from the data of the MFW scales.

A detailed time record of the MFW activity was continuously run. The time record included the following work operations and activities:

– hay loading in the process store by means of HON loader,
– maize silage loading in the process store by HON loader,
– passing 110 m to concentrates bin,
– filling MFW with concentrates from the bin under parallel mixing of the box content,
– passing 108 m to process store of brewer grains under parallel mixing of the box content,
– filling the box with brewer grains from the process store by HON loader under parallel mixing of the box content,
– passing 90 m to the trough silo of luzerne haylage under parallel mixing of the box content,
– lowering the box to position for filling or tipping the interposed process bin and lifting the cutting device or rotary cutter,
– extracting and loading luzerne haylage by means of the cutting device or rotary cutter,
– lifting the box to the transport position or lifting the interposed process bin and weighing the quantity of extracted feed,
– passing 135 m to the trough silo of luzerne haylage under parallel mixing of the box content, lowering the box to the position for filling or tipping the interposed process bin and lifting the cutting shield or the rotary cutters,
– extracting and loading clover haylage by means of the cutting device or rotary cutter,
– lifting the box to the transport position or lifting the interposed process bin and weighing the quantity of the extracted quantity of feed,
– mixing all loaded components (about 2–3 min, depending on the attendance),
– driving to the stable (35–70 m)
– TMR distribution in the stable,
– drive to the process storage (100–230 m).

The machine capacity performing each operation was ascertained by the calculation utilising the above mentioned time chronometric data.

When investigating the homogeneity of the distributed total mixed ration, average samples were taken of the distributed feed from the measuring

Figure 1. Individual parts of the separator serving to ascertain the proportions of total mixed rations (TMR) particles of different sizes and for the evaluation of TMR homogeneity

Table 2. Composition of feeding ration prepared by individual mixing feeding wagons

Feed type	Feeding ration composition					
	kg/animal/day			totally kg/day		
	heifer rearing	bull fattening	dry cows	heifer rearing	bull fattening	dry cows
Hay	1.0	0.4	3.1	200	72	223
Maize silage	5.0	6.4	4.9	1000	1152	353
Concentrate mix	1.0	1.4	0.0	200	252	0
Brewer's grains	1.5	0.9	3.1	300	162	223
Leguminous-cereal haylage	7.0	0.0	8.1	1400	0	583
Clover haylage	0.0	3.2	9.7	0	576	698
Lucerne haylage	0.0	3.2	0.0	0	576	0
Minerals	0.0	0.0	0.2	0	0	14
Total	15.5	15.5	29.1	3100	2790	2095

trays amounting to the total mass of 300–350 g (10 specimens altogether).

The samples taken were entered into the four-part separator (Figure 1) following the Robert Van Saun method (Adamová 2004).

After the agitation, the mass proportion of feed was ascertained on each screen and on the separator bottom. Measuring was effectuated immediately after the distribution of feed into the trough.

The values measured were both graphically and statistically treated and the standard deviation for the individual screens was calculated. The standard deviation characterises the quality of mixing of the individual components of the feeding ration and TMR homogeneity in the trough.

All MFW were aggregated with a CASE MXU 115 tractor equipped with an installed fuel flow meter incorporating the impulse output registering the fuel flow rate within the selected time interval. The chronometric recording of the MFW activity served for the evaluation of the course of fuel consumption during the MFW work as well as of the total consumption of individual cycles.

The power input of tractor PTO-shaft was taken off by means of a tensometric shaft and evaluating device.

In the tests it was not possible to exclude some factors disturbing the smooth course of the mixing feeding wagon operation. It concerns e.g. the way of pulling up the wagon to the wall of the stored silage and the thickness of the extracted feed layer, time lost due to the measurements and by the operator, and similar. The measured data served to establish normative values which would ensure the aim of achieving the maximal objectivity of the results acquired. The normative values for each of the fol-

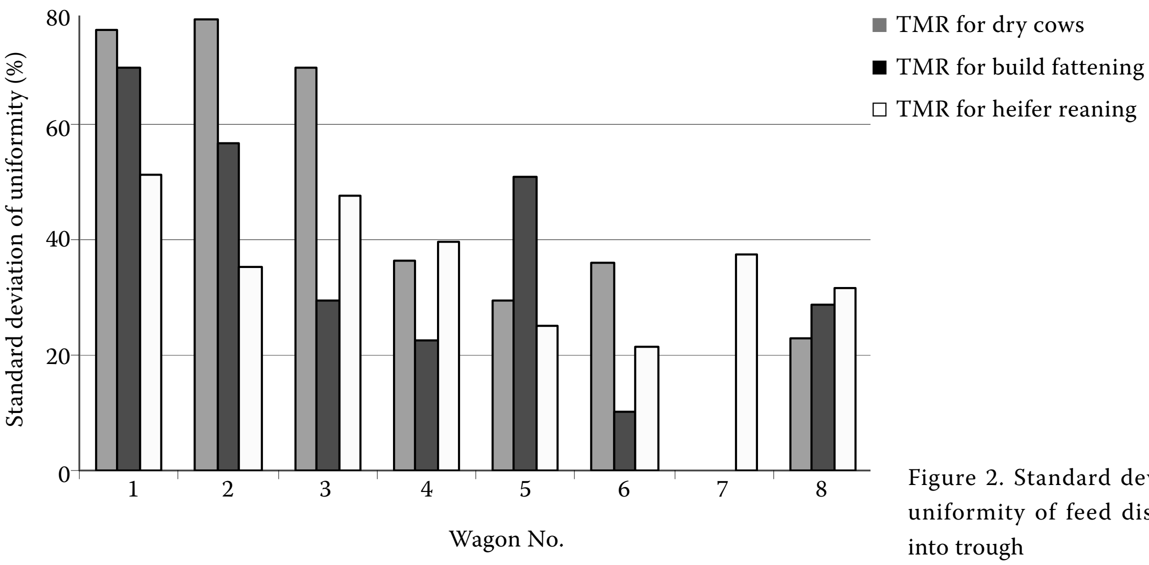

Figure 2. Standard deviation of uniformity of feed distribution into trough

Table 3. Homogeneity of total mixed rations (TMR) prepared and distributed for various cattle categories

Size of screen apertures	TMR composition	Wagon No.							
		1	2	3	4	5	6	7	8
		average mass of TMR particles on screens (converted to the total sample mass 330 g) (g)							
19 mm	dry cows	198.6	214.6	218.7	218.7	231.4	217.0		209.5
7.8 mm		67.2	53.1	49.6	50.6	39.2	54.0		57.3
1.3 mm		56.9	50.1	53.7	50.6	49.3	47.0		55.3
Bottom		8.3	12.3	9.1	10.1	10.1	10.0		7.9
19 mm	bull fattening	133.8		81.3	80.5	75.0	94.3		83.0
7.8 mm		99.6		128.7	138.2	146.0	129.0		139.3
1.3 mm		81.5		105.5	96.4	96.0	87.0		93.9
Bottom		16.1		14.5	14.9	13.0	14.0		11.9
19 mm	heifer rearing	124.8	110.3	147.7	148.7	138.1	137.2	108.7	119.3
7.8 mm		127.0	119.2	86.3	96.5	103.6	103.7	134.2	116.3
1.3 mm		76.0	87.7	84.4	73.9	78.2	77.5	78.3	79.5
Bottom		9.0	11.8	10.6	10.8	10.2	12.6	9.8	8.9

lowed up parameters were cleared from parasitical influences and on their basis a model course of preparation and distribution of TMR and its graphic form were subsequently elaborated. In these model examples, all activities (passages, mixing times etc.) for all MFW tested were defined so as to conserve a uniform procedure of preparing the feeding ration; the time consumption of the individual operations corresponds to the values measured or is equalised for all wagons (e.g. time of passages).

RESULTS AND DISCUSSION

The uniformity of the feed distribution with individual feeding wagons into the trough expressed by the standard deviation is plotted in Figure 2. Practically all MFW manifest a high variability of the feed mass distributed into the feeding trough. Here, the least balanced proved to be the TMR with a high proportion of hay (average value of standard deviation 49.9%). As concerns the design of the mixing elements better results were achieved with MFW utilising horizontal mixing augers (average standard deviation 33.7%). Vertical mixing augers distributed feed into the trough at an average standard deviation of 61.3%. Better results were achieved with the MFW with two vertical augers (average standard deviation 56.8%) than with the MFW equipped with one auger (average standard deviation 65.8%).

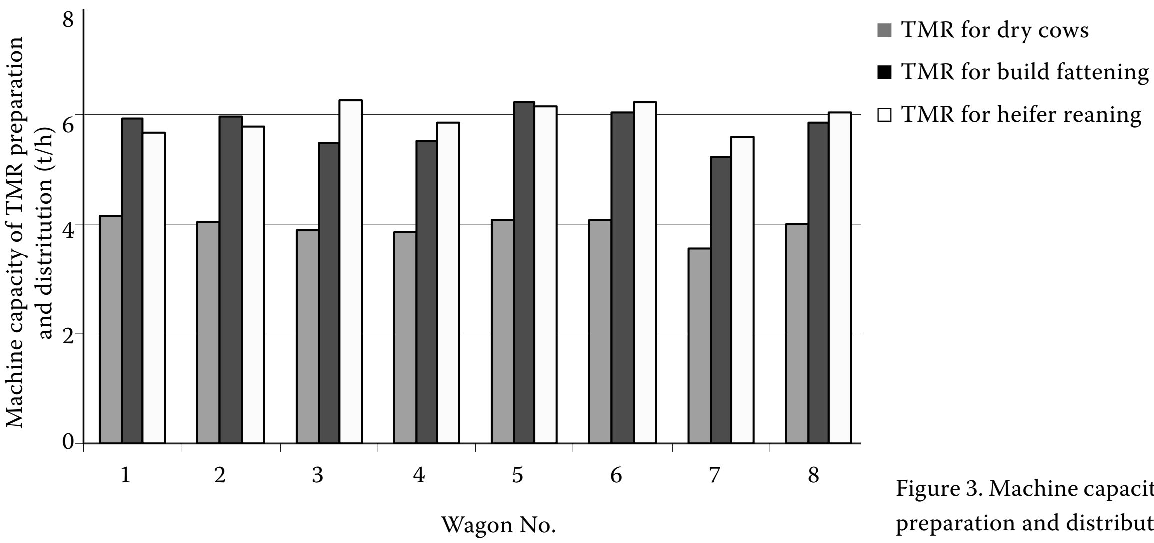

Figure 3. Machine capacity of TMR preparation and distribution

Table 4. Uniformity of distribution of TMR particles of different size on separator screens when taking in to account all values measured

Separator screen	Wagon No.							
	1	2	3	4	5	6	7	8
	average standard deviation for all TMR (%)							
19 mm	16.3	14.9	33.0	19.8	16.4	9.5	20.0	23.7
7.8 mm	13.4	15.1	26.0	12.7	14.0	18.6	7.8	12.0
1.3 mm	9.2	10.9	11.1	10.0	12.5	13.4	3.0	10.0
Bottom	17.9	21.1	30.2	20.1	15.0	21.0	15.1	19.4

These results differ from the results of the tests performed by the DLG (DLG 2006), which present substantially better values. The reason is evidently due to the methodology chosen. It is likely that the TMR distribution was controlled by an operator in the DLG tests and the results obtained were more influenced by his skill and experience than by the MFW features.

By and large, it can be stated that practically no feeding wagon working in the mode of work without operator's intervention fulfils the requirements on the uniformity of feed distributed into the feeding trough, and that the distribution always has to be controlled by an operator.

Homogeneity of the distributed TMR was evaluated for the feeding rations prepared for individual categories of cattle in accordance with the prescriptions as resumed in Table 2.

For its evaluation, the screen separator was utilised shown in Figure 1. The evaluation concerned the uniformity of the dislocation of particles of different sizes on the individual screens in different places of the feeding trough. The results, with respect to the mass proportion of feed on the individual screens (average from 10 measurements for each TMR), are presented in Table 3. Besides this, the uniformity was evaluated of the dislocation of the feed portions of different masses on the individual screens, altogether in 10 different positions of the feeding trough for each MFW and each TMR. These results were elaborated altogether as shown in Table 4, where the calculated average standard deviations are presented of the dislocation of the feed particles on the individual screens embracing all distributed TMR.

All evaluated MFW achieved very good results with respect to the uniformity of the proportions of particles of different lenghts on the individual positions of the feeding trough. Standard deviation of the proportion of the feed particles on the individual screens was lower than 20% in most cases as evident in Table 4. This offers evidence for a very good mixing efficiency of all MFW that were followed up. The influence of different working elements on TMR homogeneity also was not ascertained either.

The mass proportion of the particles on the screen with greatest appertures could testify of the intensity of intervention of MFW working elements on the feed structure. The more intensive was this interven-

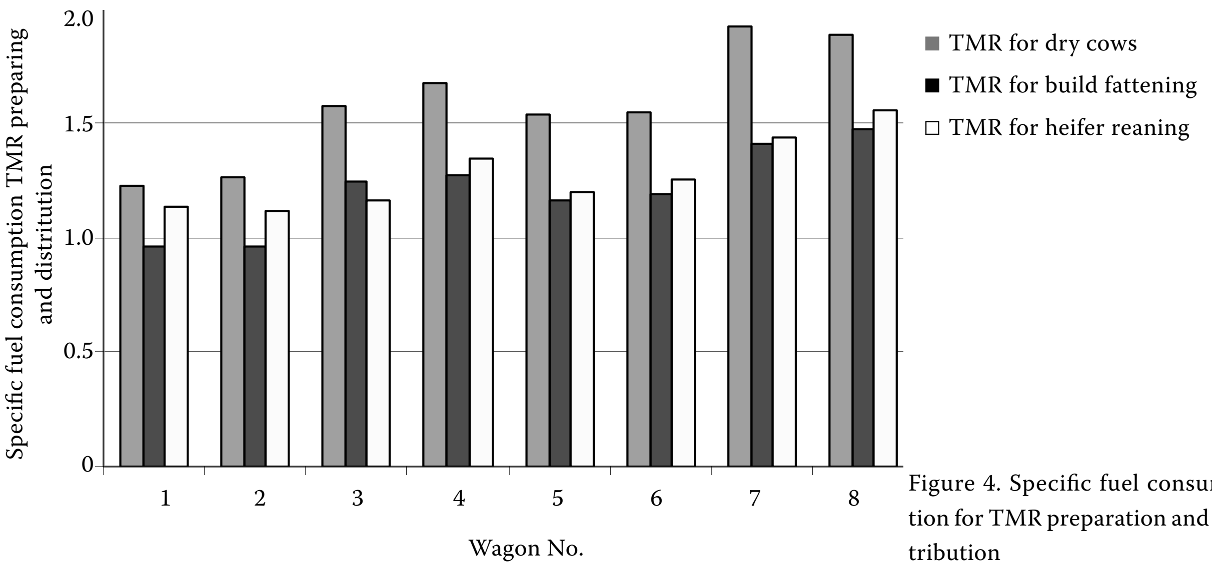

Figure 4. Specific fuel consumption for TMR preparation and distribution

Table 5. Values of selected parameters for the work operation ride incl. mixing, TMR for heifer rearing

Wagon No.	Total riding distance (m)	Average speed (km/h)	Average fuel consumption (l/h)	Feed mass in the MFW (kg)	Total mass of the set (kg)
1	1 390	7.81	11.37	1 765	16 015
2	1 253	7.41	12.33	3 620	19 420
3	1 462	9.04	11.54	2 858	15 758
4	1 460	8.82	12.08	3 236	16 936
5	1 456	9.18	11.94	2 920	14 520
6	1 450	9.09	14.10	3 122	8 072
7	1 600	8.88	11.47	3 265	9 565
8	1 450	8.69	15.32	3 170	8 670

tion, the larger was the proportion of shorter feed particles in the total TMR; the smaller was the mass proportion of the feed articles on the screen with the largest appertures. The data of Table 3 allow to deduce that the assumption of the intervention of vertical mixing augers on feed being less damaging was not confirmed, because the mass proportion of feed on the screen with the largest apertures is comparable. The mixing units with horizontal augers achieved even slightly better results as compared with the mixing units with vertical augers. It will be necessary to intensify and extend the research work in this direction in the future.

The establishing of the machine capacity of TMR preparation and distribution of fuel and lubricant consumption were found in detailed chronometric recording. The time records were cleared from non productive activities and subsequently normative values were calculated for each work operation.

Such values elaborated and calculated in view of finding the machine capacities for TMR preparation and distribution are resumed in the graphic in Figure 3. The data acquired enable to deduce that no great differences exist between various MFW with respect to their output in preparing and distributing TMR; average machine capacities found

MFW No.	5	Total time of TMR preparation and distribution (s)	1845
Date of measuring	27.4.2006	Machine capacity of TMR preparation and distribution (t/h)	4.09
Time of measurement start	9:01:18	Specific fuel consumption for TMR, prepar. and distribution (l/t)	1.53
Feeding cycle	dry cows	Total mass of feed in the MFW (kg)	2095

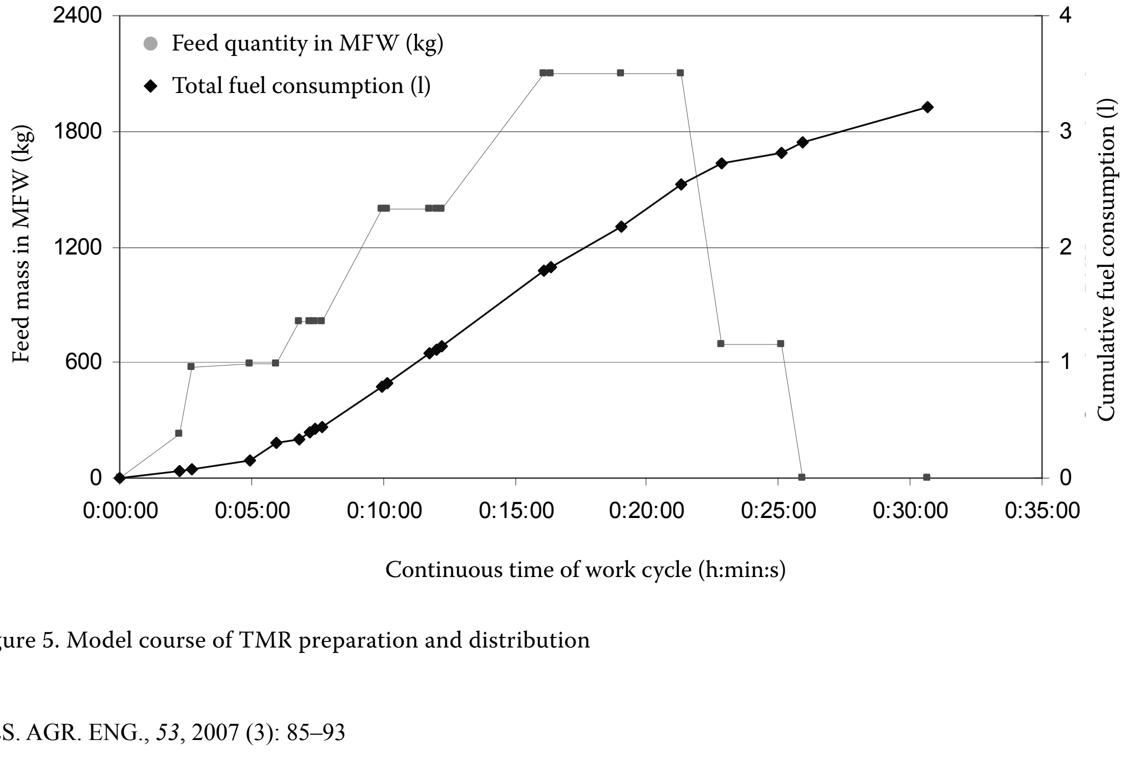

Figure 5. Model course of TMR preparation and distribution

throughout all the measurements vary in the range of 4.79–5.48 t/h.

Larger differences were found in the evaluation of specific fuel consumption both for various mixing feeding wagons and for various TMR compositions as apparent from the Table 5. The least average specific fuel consumption for TMR preparation and distribution was ascertained with MFW equipped with vertical mixing augers (1.10–1.11 l/t). MFW equipped with one horizontally mounted mixing auger showed a slightly higher fuel consumption (1.30–1.43 l/t). The highest specific fuel consumption was found with MFW with two parallel mixing augers (1.59–1.63 l/t). The highest specific fuel consumption was measured with the selfpropelled MFW. A higher specific consumption was found also with all MFW evaluated when preparing TMR with a higher proportion of the hay content (Figure 4).

On the basis of the established procedure of TMR preparation, the values of chronometric recordings, and the calculated normatives, model time records were created of TMR preparation and distribution for each mixing feeding wagon participating in the tests. These data, among others, were treated in the form of graphics visualising the cumulative increase of the feed mass in the wagons and the cumulative increase of fuel consumption during the preparation and distribution of TMR. An example of such a graphic is presented in Figure 5.

The average power consumption taken off by individual MFW varied in the range of 16.9–32.6 kW. The maximum measured values of the power intake were slightly higher; however, they did not exceed the value of 40 kW. In this sense, the values measured are lower than the values found by the DLG. Several reasons can account for this fact. Following our experience concerning the intake of power and the machine capacity in extracting feed from storage, these are influenced by the experience and skill of the operators, the type and properties of the feed treated and the technical state of the working elements of the mixing feeding wagons. Blunt knives of the rotary cutter, e.g., can cause an increase of the power consumption by as much as 35%.

The work performed shows that the manufacturers of mixing feeding wagons steadily pursue the improvement of the product features and the elimination of their possible deficiencies. Their efforts have resulted in relatively levelled values of the important operational parameters, even when comparing mixing feeding wagons presenting different technical and conceptual solutions.

In concluding it should be also stated that the testing was undertaken under relatively equal conditions, each feeding wagon, however, prepared and distributed only three full feed boxes maximum. This is not enough for acquiring unambiguous results. It is therefore necessary to perceive and interpret the results presented here with the awareness of this limitation.

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Received for publication November 1, 2006
Accepted after corrections May 31, 2007

Abstrakt

Vegricht J., Miláček P., Ambrož P., Machálek A. (2007): **Parametrická analýza vlastností vybraných krmných vozů.** Res. Agr. Eng., **53**: 85–93.

Celkem 9 různých míchacích krmných vozů (MFW) bylo sledováno za stejných podmínek při přípravě zakládání směsné krmné dávky (TMR) pro tři různé kategorie skotu. Byla sledována rovnoměrnost založení krmiva do žlabu, homogenita založené TMR, výkonnost při oddělování a nakládání krmiva, míchání a zakládání TMR do žlabu, spotřeba pohonných hmot a potřebný příkon. Nejméně vyrovnaná byla TMR s vysokým podílem sena (průměrná hodnota směr.odchylky 49,9 %). Lepší výsledky dosáhly MFW s horizontálními míchacími šneky (průměrná směr. odchylka 33,7 %). MFW s vertikálními šneky zakládaly krmivo do žlabu s průměrnou směrodatnou odchylkou 61,3 %.

Směrodatná odchylka podílu částic krmiva na jednotlivých sítech separátoru, která je měřítkem homogenity TMR, byla ve většině případů nižší než 20 %. To svědčí o velmi dobré účinnosti míchání všech sledovaných MFW. Rozdílný vliv různě řešených pracovních orgánů MFW na homogenitu TMR nebyl prokázán. Z hlediska výkonnosti přípravy a založení TMR nejsou mezi jednotlivými MFW velké rozdíly a průměrné výkonnosti ze všech měření se pohybují v rozmezí 4,79–5,48 t/h. Nejmenší průměrná měrná spotřeba pohonných hmot na přípravu a založení TMR byla zjištěna u MFW s vertikálními míchacími šneky (1,10–1,11 l/t). MFW s jedním horizontálně uloženým míchacím šnekem vykázaly spotřebu poněkud vyšší (1,30–1,43 l/t). Největší měrná spotřeba byla zjištěna u MFW se dvěma paralelně uloženými míchacími šneky (1,59–1,63 l/t).

Klíčová slova: míchací krmné vozy; krmení skotu; směsné krmné dávky; výkonnost; spotřeba pohonných hmot

Corresponding author:

Doc. Ing. Jiří Vegricht, CSc., Výzkumný ústav zemědělské techniky, v.v.i., Drnovská 507, 161 01 Praha 6-Ruzyně, Česká republika
tel.: + 420 233 022 281, e-mail: jiri.vegricht@vuzt.cz