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Analysis of milk traits in relation to feeding level and organization in a herd of high-yielding cows

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The aim of the study was to determine factors influencing the balance of energy and protein in high-yielding cows. Daily milk yield, lactation number and month of lactation were analysed. The study was carried out in a herd with yield of 11,000 kg milk/year, on 517 lactating cows. The cows were divided into four feeding groups. They were fed TMR calculated for levels of milk production, as follows: group 1 – for 45 kg, group 2 – for 35 kg, group 3 – for 26 kg and group 4 – for 20 kg. The actual mean milk yield for these groups was 49.1 kg, 38.1 kg, 26.3 kg and 17.5 kg per day. Each group consisted of cows in their first to sixth lactation and in their first to tenth month of lactation. No significant differences were noted in daily milk yield between lactation numbers or months of lactation. As milk yield increased in the groups, the content of fat and protein decreased. The estimated balance of energy, based on the protein percentage in the milk, was negative for nearly the entire lactation in group 1, for the first four months of lactation in group 2, for the first two months in group 3, and in the second month of lactation for group 4. Group 1 was divided into three subgroups according to yield: up to 45 kg, 45-50 kg and 50 kg or more. Energy was estimated to be well-balanced only in the first subgroup. The balance of energy in the cows was strongly determined by daily milk yield, and to a lesser degree by the month of lactation. Protein, based on the concentration of urea in the milk, was well-balanced in groups 1 and 2. In groups 3 and 4, the recommended level of protein in the rations was exceeded by 10-20%.

KEY WORDS: cow / milk yield/ protein concentration / fat concentration / urea concentra tion / balance of energy / balance of protein

Diet is one of the most important environmental factors influencing the productivity of cows, the chemical composition of their milk, and production efficiency [17]. Due to the substantial variation between cows in a herd in terms of daily milk yield at a given

time, there is a need to differentiate individual feed rations. This applies in particular to the amount of concentrate feed in the ration [4, 8], which is significant in terms of both health and economics. Contemporary systems use different variants of free-stall housing and group feeding. In small herds, numbering up to 50-60 cows, the herd is generally not divided into groups; there is only one group of cows in milk. In larger herds, on the other hand, the cows are usually divided into several groups. The number and size of the groups is determined by the layout of the barn and the number of stalls in the milking parlour. When groups are too large the welfare of the animals declines due to the long time spent in the waiting area before milking [28]. Dividing the herd into groups facilitates organization of feeding and enables appropriate rationing of concentrate feed [13, 15]. Although issues related to the organization of feeding have great practical significance, there are no scientific studies regarding this question. In the available literature only popular science articles discuss certain aspects of group feeding of cows [13, 15, 16, 19].

The aim of the study was to determine the factors influencing the balance of energy and protein in high-yielding cows receiving varying TMR rations. An analysis was performed of the effect of lactation number and stage of lactation on the occurrence of deficiencies or excesses of nutrients.

Material and methods

In the years 2011-2013 the yield in the analysed herd remained at a level from 9,500 to 11,000 kg/cow (Tab. 1). Data from the test-day milking records of 517 cows in milk, obtained from the Polish Federation of Cattle Breeders and Dairy Farmers, were used for the calculations.

Table 1
Mean yield in the herd (A) and the number of cows subject to use value assessment in the Wielkopolska Voivodeship (B) in the years 2011-2013 [22]

Herd	Year	Mean number of cows	Mean annual yield (kg)			Concentration in milk (%)	
			milk	fat	protein	fat	protein
A	2011	668.60	9606	376.20	322.80	3.92	3.36
	2012	737.40	10 339	398.20	345.00	3.85	3.33
	2013	700.80	10 988	436.00	357.60	3.96	3.25
B	2011	121 060	7949	322	267	4.06	3.36
	2012	126 380	8148	333	277	4.09	3.40
	2013	128 676	8164	334	277	4.09	3.39

The study was carried out in a herd of 700 cows, with annual yield of about 11,000 kg/cow. From the entire herd 517 cows in milk were selected. Statistical analysis of the results from the herd was performed on numerical data on daily milk yield during the period from May 2013 to February 2014. Limiting the study to a single herd made it possible to ensure identical feeding and environmental conditions. The herd was divided into eight feeding groups. Four groups consisted of cows in milk, two of dry cows (in the initial and final stage of the dry period), one of cows in the peripartum period, and one of cows receiving medical treatment. Only cows in milk were selected from the herd, and these were divided into groups on the basis of daily yield. Feed was supplied in the form of TMR, calculated for yield of 45 kg of milk for group 1, 35 kg for group 2, 26 kg for group 3, and 20 kg for group 4 (Tab. 2).

Table 2
TMR characteristics in each feeding group

Group	Energy concentration (MJ/kg)	Protein concentration (g/kg)	Fibre content (%)	Dry matter content (%)	Ration calculated for milk production (kg)
1	7.40	174.50	14.00	49.21	45
2	7.33	167.20	13.44	44.46	35
3	6.79	147.90	17.64	35.97	26
4	5.85	143.50	22.59	30.19	20

TMR for each group differed in composition and nutritional value. The feed ration for group 1 had the highest content of dry matter, energy and protein, and the lowest content of fibre. Each successive group received feed of decreasing nutritional value, adjusted to the decreasing daily milk yield. The subject of the analyses was cows in milk, in four feeding groups. The age distribution in the groups, based on lactation number, is presented in Table 3.

The protein content in the milk was used to estimate the degree to which the feed met the requirement for energy in each feeding group, and urea content was used to evaluate the protein percentage in the milk. The results were interpreted using values given by Ziemiński and Juszczak [29] and by Brade and Brade [5].

The cows were milked three times a day. Basic milk parameters, i.e. content of fat, protein and urea, were determined by automated infrared analysis, using a MilkoScan FT-120 analyser (Foss Electric, Hillerod, Denmark). The hygienic condition of the milk was evaluated based on the somatic cell count, using a Somacount-150 device.

Table 3
Number of cows in successive lactations in each feeding group

Lactacion	Number of cows in group				Total	%
	1	2	3	4		
1	11	110	26	39	186	36.0
2	93	46	16	15	170	32.9
3	40	25	6	13	84	16.2
4	20	13	5	5	43	8.3
5 and 6	19	8	4	3	34	6,6
Total	183	202	57	75	517	100.0
%	35.4	39.1	11.0	14.5	100	–

Analysis of variance (model 1 – fixed effects) was performed, and in the case of differences between means the significance of differences for pairs of means was tested. The computations were performed using the SAS statistics package [24], with the MEANS, UNIVARIATE and GLM procedures and the LSD test.

The analysis was carried out according to two similar linear models, taking into account the effects of feed rations and lactation number and the effects of feed rations and month of lactation.

Statistical model for the TMR feeding rations and lactation number:

$$y_{ijkmn} = \mu + MG_i + HY_j + TMR_k + L_m + e_{ijkmn}$$

Statistical model for the TMR feeding rations and month of lactation:

$$y_{ijkon} = \mu + MG_i + HY_j + TMR_k + ML_o + e_{ijkon}$$

where:

y_{ijkmn}, y_{ijkon} – phenotypic values of traits
μ – grand mean
MG_i – milk yield groups (i = 1, 2, 3, 4)
HY_j – herd-year (j = 1, 2, 3, ..., 8)
TMR_k – TMR (k = 1, 2, 3, 4)
L_m – lactation number (m = 1, 2, 3, 4, (5+6))
ML_o – month of lactation (o = 1, 2, 3, ..., 10)
e_{ijkmn}, e_{ijkon} – random error

Results and discussion

The herd was characterized by high and increasing yield of milk and its components (Tab. 1). From 2011 to 2013 the yield in the herd increased by 1,382 kg of milk, with a slight increase in fat content (0.04 p.p.) and a decrease in protein content (0.11 p.p.). Yield in

the herd was 1,657 kg higher than the average for the Wielkopolska Voivodeship in 2011, and in 2013 this difference increased to 2,824 kg.

In the first group, which numbered 183 cows, the average daily yield was 49.1 kg, with the yield of 13 cows exceeding 60 kg. Analysis of the composition of each group revealed that they were varied in terms of both lactation number (Tab. 3) and stage of lactation (Tab. 4). The herd contained cows in lactations 1 to 6 (Tab. 3). Primiparous cows and cows in their second lactation were most numerous, and the fewest cows were in lactations 4-6. In group 1 the most cows were in their second lactation, accounting for over half of the group, while in the second group over half of the group consisted of primiparous cows. The size of the groups was varied, with the most cows in the second (202) and first (183) groups. Groups 3 and 4 were considerably smaller. Each group contained cows in different stages of lactation (Tab. 4).

Table 4
Percentage of cows according to stage of lactation in feeding groups

Group	Percentage of cows in each stage of lactation			Total
	<100	100-200	>200	
1	50.5	41.1	8.4	100
2	23.6	39.7	36.7	100
3	28.0	43.3	28.7	100
4	50.6	33.6	15.8	100

In group 1, 50% of cows were in their first 100 days in milk, over 40% in days 100-200, and 8.4% in the final stage of lactation. A considerable number of cows had very high yield for many months; for example, the yield of one of the cows on day 238 of the second lactation was 60.3 kg, and that of another, on day 304 of the third lactation, was 57.3 kg. In groups 2 and 3 the percentages of cows in different stages of lactation were similar. In group 4 half of the cows were in the initial stage of lactation and only 15.8% were in the final stage. The fairly atypical composition of group 4 was due to the fact that cows with low genetic potential, mainly primiparous cows prior to selection, constituted over half of this group. The division of the herd into groups was asymmetrical. The most numerous were groups 1 and 2, i.e. the cows with the highest yield, accounting for 74.5% of the herd, while the groups with lower yield (3 and 4) accounted for only 25.5% of the herd.

Characteristics of the daily milk yield and its composition in each of the feeding groups are presented in Table 5.

Substantial variation was observed in milk yield between groups. This indicates that the herd was divided correctly. In group 1 the mean yield was 49.1 kg of milk, which was 4.1 kg more than the estimated value of the feed ration. In group 2 the average yield was 3.1 kg higher as compared to the value for the feed ration. Only in group 3 did the milk yield corre-

Table 5
Basic characteristics of milk performance in feeding groups

Group	Number of cows	Statistical indicator	Milk yield (kg)	Content (%)		Urea content (mg/dm^3)
				fat	protein	
1	183	$\overline{x}$	49.10	3.68	3.07	238.0
		SD	7.16	0.61	0.24	51.4
		V	14.60	16.50	7.70	21.6
2	202	$\overline{x}$	38.1	3.80	3.26	252.0
		SD	4.7	0.61	0.27	75.6
		V	12.3	16.10	8.40	30.0
3	57	$\overline{x}$	26.30	4.11	3.34	335.0
		SD	5.33	0.65	0.31	129.3
		V	20.30	15.90	9.20	38.6
4	75	$\overline{x}$	17.50	4.26	3.34	370.0
		SD	5.04	0.62	0.32	77.0
		V	28.80	14.60	9.50	20.8

$\overline{x}$ – mean; SD – standard deviation; V – coefficient of variation

spond to the value of the feed ration, whereas in group 4 the actual yield was 2.5 kg below the value for the TMR level.

Fat and protein concentrations in the milk were lowest in group 1, and increased gradually in successive groups. This may indicate a deficiency of components for fat and protein production in the feed for the cows with the highest yield. The mean urea content in the milk was varied. In groups 1 and 2 it was similar, at about 250 mg/dm^3, and was within the normal range. In groups 3 and 4, however, it substantially exceeded 300 mg/dm^3, which indicates too much protein in the feed ration [29].

Due to the division of the herd into groups the mean yield differed considerably between groups, by about 10 kg each time. The differences between groups equally affected cows in successive months of lactation (Fig.). This indicates that the division of the herd into groups according to the criterion of milk yield was correct.

Within groups, however, there was substantial variation (Tab. 6). The highest variation was observed in group 1, because it included all cows after calving and all cows with the highest yield. For these reasons 6.5% of the group consisted of cows with yield of under 40 kg milk/day, and 44.2% consisted of cows with yield of over 50 kg/day. Therefore we performed a statistical analysis of the chemical composition of the milk in group 1 according to three yield sub-classes: up to 45 kg, 45-50 kg and 50 kg or more (Tab. 7).

Only in the milk of cows with yield of up to 45 kg did the protein content indicate a correct level of energy in the feed [29]. Feeding of cows with yield of over 50 kg/day is difficult [1, 9, 20, 21, 26]. This is due to two factors, one of which is the insufficient concentration of energy in livestock feed. On the other hand, increasing the concentration of energy by including a larger proportion of concentrate feed in the feed ration leads to di-

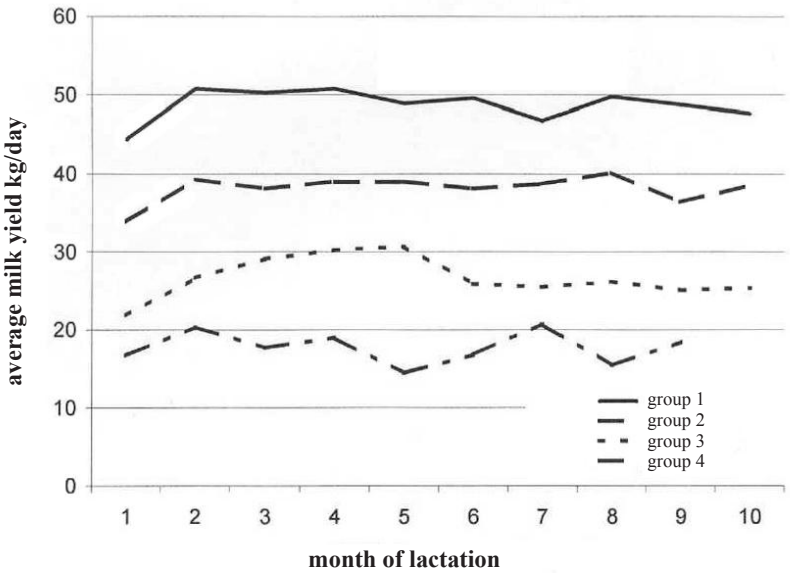

Fig. Average daily milk yield in successive months of lactation

Table 6
Distribution of milk yield in feeding groups

Daily milk yield (kg)	Percentage of cows in group			
	1	2	3	4
<15.0	–	–	–	34.7
15.0-20.0	–	–	–	37.2
20.0-25.0	–	–	49.1	18.7
25.0-30.0	–	2.7	32.2	6.7
30.0-35.0	4.3	24.0	10.2	2.7
35.0-40.0	2.2	39.5	8.5	–
40.0-45.0	23.0	27.4	–	–
45.0-50.0	26.3	4.9	–	–
50.0-55.0	24.6	1.5	–	–
55.0-60.0	13.1	–	–	–
≥60.0	6.5	–	–	–
Total	100	100	100	100

gestive disorders in cattle. The proportion of energy in concentrate feed should not exceed 50% of the dry matter in the feed ration [6, 8, 14]. Apart from balancing the feed ration in terms of energy and protein, additives stabilizing the pH of the rumen are essential [12].

The mean urea content was similar in the milk of all groups and remained within the normal range, which indicates correct balance of the feed rations in terms of protein content [29].

Table 7
Chemical composition of milk depending on daily milk yield in cows in group 1

Milk yield (kg/day)	Number of cows	Statistical indicator	Average milk yield (kg)	Content (%)		Urea content (mg/dm^3)
				fat	protein	
<45	54	$\overline{X}$	41.1	3.83	3.23	240
		SD	4.2	0.52	0.26	45
		V	10.3	12.5	8.00	19
45-50	48	$\overline{X}$	47.4	3.73	3.04	239
		SD	1.3	0.66	0.19	52
		V	2.8	17.6	6.20	22
>50	81	$\overline{X}$	55.4	3.54	2.97	236
		SD	4.2	0.60	0.18	54
		V	7.6	17.0	6.00	23
Total	183	$\overline{X}$	49.1	3.68	3.07	238
		SD	7.2	0.61	0.24	51
		V	14.6	16.50	7.70	21

$\overline{X}$ – mean; SD – standard deviation; V – coefficient of variation

To meet the increased energy requirements of cows, next-generation feed additives have been developed and tested. One of these is exogenous fibrolytic enzymes [2, 3, 20]. Morel et al. [18] showed that the degree to which the energy requirements of dairy cows are met affects the yield and protein content of milk. The literature indicates a high probability of energy deficiencies in high-yielding cows in the initial stage of lactation [6, 7, 10, 11, 14, 23, 25]. Our results demonstrate that the energy deficit may persist for a much longer period of lactation.

Analysis of daily milk yield in successive months showed no statistically significant differences between groups. An exception was the difference noted between the first month of lactation and the remaining months in group 2.

The mean protein content in the milk during lactation in each group indicates that energy deficiencies occurred at different times (Tab. 8). In the table the numbers in bold represent values indicating an energy deficiency in the feed ration.

The deficiency was greatest in group 1 and was observed in nearly the entire lactation; in group 2 it persisted for the first four months of lactation; in group 3 for the first two months; and in group 4 only in the second month. Thus it can be concluded that it is not the stage of lactation but daily milk yield that determined the energy balance in a given group.

In group 1 the differences between months of lactation were often statistically significant (Tab. 9).

Table 8

Mean protein content in milk in each month of lactation in feeding groups

Month of lactation	Protein content in milk in group			
	1	2	3	4
1	3.23	**3.05**	**2.98**	3.22
2	**2.91**	**2.89**	**3.19**	**3.15**
3	**3.02**	**2.94**	3.25	3.37
4	**3.02**	**3.11**	3.20	3.42
5	**3.05**	3.26	3.21	3.27
6	**3.04**	3.31	3.29	3.27
7	**3.19**	3.39	3.70	3.61
8	3.26	3.33	3.39	3.56
9	**3.13**	3.35	3.47	3.50
10	**3.18**	3.45	3.42	no data

Values in bold indicate an energy deficiency in the feed ration

Table 9

Differences and significances of differences in protein content in the milk of group 1 cows between months of lactation

Month of lactation	Differences or significances of differences between months of lactation									
	1	2	3	4	5	6	7	8	9	10
1	–	**XX**	**XX**	**XX**	**XX**	**XX**	ns	ns	ns	ns
2	0.32	–	ns	ns	**X**	**X**	**XX**	**XX**	**X**	**X**
3	0.21	0.11	–	ns	ns	ns	**X**	**X**	ns	ns
4	0.21	0.11	0	–	ns	ns	**X**	**X**	ns	ns
5	0.18	0.14	0.03	0.03	–	ns	ns	**X**	ns	ns
6	0.19	0.13	0.02	0.02	0.01	–	**X**	**X**	ns	ns
7	0.04	0.27	0.17	0.17	0.14	0.15	–	ns	ns	ns
8	0.03	0.35	0.24	0.24	0.21	0.22	0.07	–	ns	ns
9	0.10	0.22	0.11	0.11	0.08	0.09	0.06	0.13	–	ns
10	0.05	0.27	0.16	0.16	0.13	0.14	0.01	0.08	0.05	–

ns – statistically non-significant difference
X – statistically significant difference at $P<0.05$
XX – statistically significant difference at $P<0.01$

In group 2 as well the differences in protein content in the milk between the first months of lactation (1 to 4) and the remainder of lactation were confirmed statistically (Tab. 10). The results obtained in group 2 correspond most closely to the model presented in the literature [11, 23, 25].

The results presented indicate the difficulty of selecting feed material for TMR for cows with the highest daily milk yield as well as difficulties in appropriate organization of feeding.

Table 10

Differences and significances of differences in protein content in the milk of group 2 cows between months of lactation

Month of lactation	Differences or significances of differences between months of lactation									
	1	2	3	4	5	6	7	8	9	10
1	–	ns	ns	ns	**XX**	**XX**	**XX**	**XX**	**XX**	**XX**
2	0.16	–	ns	**XX**	**XX**	**XX**	**XX**	**XX**	**XX**	**XX**
3	0.11	0.05	–	**X**	**XX**	**XX**	**XX**	**XX**	**XX**	**XX**
4	0.06	0.26	0.17	–	**X**	**XX**	**XX**	**XX**	**XX**	**XX**
5	0.21	0.37	0.32	0.15	–	ns	**X**	ns	ns	**X**
6	0.26	0.42	0.37	0.20	0.05	–	ns	ns	ns	ns
7	0.34	0.50	0.45	0.28	0.13	0.08	–	ns	ns	ns
8	0.28	0.44	0.39	0.22	0.07	0.02	0.06	–	ns	ns
9	0.30	0.46	0.41	0.24	0.09	0.04	0.04	0.02	–	ns
10	0.40	0.56	0.51	0.34	0.19	0.14	0.06	0.12	0.10	–

ns – statistically non-significant difference
X – statistically significant difference at P<0.05
XX – statistically significant difference at P<0.01

The analysis of daily yields in successive months of lactation did not reveal statistically significant differences within the four groups (Fig.), except for group 2, for which a difference was noted between the first month and the remaining months. On the other hand, the mean protein values in the groups (Tab 8) show an energy deficiency which can be seen in different stages of lactation.

Our study confirms the statement by Walter [27] that the development of a feeding system for cows according to principles of 'precision agriculture' is still far from being achieved.

The results of the study indicate that the division of the herd into feeding groups evens the level of milk yield within groups; however, particularly for the highest-yielding cows, there is still variation within groups. Variation in milk yield persists for the entire lactation; the energy deficiency depends on daily yield, not on the stage of lactation. Given the current level of the feed base on the farm, a balance of energy for the feed rations is possible up to a yield of about 45 kg, but the ration for the group of cows with the highest yield must be corrected. There was no protein deficiency in the feed ration for any of the groups analysed.

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