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Productivity and adaptation ability of Holstein cattle of different genetic selections

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Abstract: The purpose of the research was to compare economically useful traits of Holstein cows of different selections. The results show that the German and Australian selections were superior to the Danish and American cows in terms of their growth (at 36 months of age, the body weights of the German and Australian cows were 36.5 and 27.6 kg greater than the Danish cows and 24.3 and 15.4 kg greater than the American cows, respectively). Maximum milk yield was obtained from the American and German cows (25,220 and 24,861 kg). Their milk also had higher fat content. The maximum protein content was found in the milk of the Australian and American cows (3.47% and 3.38%). The calf crop from the American, Danish, German, and Australian cows was 87%, 82%, 84%, and 83%, respectively. The Danish and Australian cows had higher erythrocyte, total protein, and phagocytosis indices, but the German and American cows had higher germicidal and lysozyme activity indices. The level of profitability of milk production from the cows of American and German selections was higher by 10.8%–11.3%. However, acclimatization process modeling helped to establish that for long-term economic planning, the Danish Holsteins should be preferred.

Key words: Holstein, selection, adaptation, productivity, milk, profitability

1. Introduction

Development of any trait of an organism is determined by heredity (genotype) and environmental conditions. It is the practice to estimate quantitative characteristics, which include milk-producing ability and fat and protein content in milk, by the phenotype and by manifestation of these characteristics in the conditions where the body grows and develops (1–7). Today, the dairy cow population in farms in the Russian Federation has 19 breeds and 23 types of stud cattle and inbreeding. Black-and-White Holstein cows account for 58%, which is the greater part of dairy cattle breeds. Holstein cows are characterized by great body weight (BW) (600–650 kg); the calf's birth weight is 37–40 kg and the calves are noted for intense growth. The average daily gain is not less than 700 g for the entire growing period and BW reaches 400 kg by the breeding period. The implementation rate of the genetic potential and the livestock output directly depend on the herd reproduction rate (8). The animals of this breed need to be further improved in their constitution, exterior, productive qualities, and adaptive ability to new climatic conditions. The study of the acclimatization abilities of various breeds allows their considerable expansion in the area due to the rational distribution of animals in different climatic zones. The adaptive ability of cattle is an important feature that determines the ability of the cows to be used in industrial technology. The important criteria characterizing the adaptation degree and its maintenance in a changing environment are the growth, development, productivity levels, and reproductive performance of the animals (9,10). The purpose of the research was to compare economically useful traits of different Holstein cows.

2. Materials and methods

The limited liability company Agricultural Enterprise Donskoe, located in the Volgograd region, is one of the leading raw milk producers in the Russian Federation. The animals were in a loose housing barn. Separate milking was done in special areas using milking parlors. The dairy complex has two milking parlors, equipped

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with two types of milking machines: 16 places with the Herringbone Parlour "Impulsa" (2006) and 36 places with the Rotary Milking Parlour "WestfaliaSurge" (2010). The Impulsa's throughput is up to 120 heads per hour and the WestfaliaSurge's throughput is up to 200 heads per hour.

In 2006, Holstein cattle was imported here from the following countries: the United States (245 heifers), Denmark (245 heifers), Germany (386 heifers), and Australia (250 heifers). The housing conditions and the feed of all of the cows were similar. The experimental animals were fed a balanced diet according to the detailed rules of the All-Russian Institute of Livestock Breeding (11).

The average daily diet consisted of 20 kg of corn silage, 4 kg of alfalfa hay, 10 kg of combined silage (cereals, legumes, etc.), 6 kg of concentrated feedstuff (wheat, barley, etc.), 1 kg of soybean cake, and 10 kg of brewer's grains. The feeding standards per head a day were at least 19 energetic feed units during days in milk (the expected producing ability was 9000 kg of milk per lactation) and depended on the weight and the age of the animal.

The reproductive ability of heifers and cows was studied using data from the farm record book. Growth and development of the animals were assessed using the data from the appraisal and farm records, which are common in a breeding farm.

Hematological parameters were determined by the following methods: hemoglobin was assessed according to the Sahli-Hellige method, the numbers of erythrocytes and leukocytes were counted in Gorjaev's chamber, total protein in serum was determined refractometrically, protein fractions were determined by SDS-PAGE according to the Laemmli method, erythrocyte sedimentation rate was determined by the Westergren method, and the alkali reserve of blood was measured according to the method described by Kondrakhin (12). The natural resistance and the immune statuses of the cows were evaluated based on the bactericidal activity of serum, the lysozyme activity of blood, and the phagocytic index (13,14).

Milk records were established on the basis of monthly milk checks. The fat content in milk was determined by Government Standard (GOST) R ISO 2446-2011. The analysis of the mass fraction of the total nitrogen and the total milk protein were performed by the Kjeldahl method (GOST 23327-98). The quantitative analysis of amino acids in milk was carried out by high-performance liquid chromatography using chromatograph LC-10 (Shimadzu, Japan) with a fluorometer and precolumn derivatization according to the manufacturer's recommendations.

The cost-effectiveness of cows of different genotypes was counted based on the annual actual and intrafarm economic effect and according to Minakov (15) using the following formulas:

$$\text{Milk of standart fat content (3,4\%), kg} = \frac{\text{Milk obtained from the first lactation, kg} \times \text{Fat content in milk, \%}}{3{,}4\%};$$

$$\text{Cost - price of 1 kg of standardfat content milk, €} = \frac{\text{Farm inputs, € per head}}{\text{Milk of standard fat content (3,4\%), kg}};$$

Milk sales proceeds, € = Milk of standard fat content (3,4%), kg × Market value of milk kg, €; Profit, € = Milk sales proceeds, € - Farm input, € pear head;

$$\text{Profitability level, \%} = \frac{\text{Profit, €}}{\text{Farm inputts, € pear head}} \times 100\%$$

The data were analyzed with Statistica 10 (StatSoft Inc., USA). Significance of the differences among the indices was determined using the criteria of nonparametric statistics for the linked populations (16). The Fischer test determined the statistical significance of the R^2 determination coefficient and the statistical reliability of the empirical nonlinear regression equations, predicting the milk yield for 305 days of lactation in Holstein cattle of different selections. Since $F > F_{crit}$, the determination coefficient is significant, and, in general, empirical regression equations are statistically reliable. Student's t-test confirmed the statistical significance of the coefficients *a* and *b* in the nonlinear regression equation $y=ax^2+bx+c$. Heteroscedasticity was tested by the Goldfeld–Quandt test: no heteroscedasticity. The Durbin–Watson test was conducted to detect autocorrelation: no autocorrelation. The Spearman rank correlation was evaluated: the rank correlation coefficient is statistically significant. The mean of a set of measurements was calculated according to the formula $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$, where $\bar{x}$ is – a mean value; $\sum_{i=1}^{n} x_i$ is – read as "the sum of all x_i with *i* ranging from 1 to n"; and *n* is the number of measurements. The residual variation is expressed as a root mean square error: $\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$. Standard error (SE) was calculated using the formula $SE = \frac{\sigma}{\sqrt{n}}$. The reliability of a sample difference (Student's t-distribution) was estimated by the test of the difference validity, which is the ratio between the sample difference and the nonsampling error. The test of the difference validity was determined by the formula

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{SE_1^2 + SE_2^2}} \geq t_{st}(d.f. = n_1 + n_2 - 2)$$

, where t is Student's t-distribution; $(\bar{x}_1 - \bar{x}_2)$ is the difference of the sample mean measurements; $\sqrt{SE_1^2 + SE_2^2}$ is the sample difference error; SE_1 and SE_2 are the nonsampling errors of the compared sample statistics; t_{st} is the standard criterion according to the t-table for the probability threshold preset depending on degrees of freedom ("probability": P < 0.05; P < 0.01; P < 0.001; not significant "ns"); n_1 and n_2 are the number of measurements in the samples compared; and *d.f.* is the degrees of freedom for the difference of two mean measurements. The potential productivity was calculated according to Shiller et al. (17) and the multiple correlation coefficients were calculated according to Volt and Rust (18) and Chen (19). To predict the milk yields of the cows imported from different countries, one can use the following nonlinear regression equations: $Y_X=7940+280X-20X^2$ (USA); $Y_X=8202-936X+334X^2$ (Denmark); $Y_X=8200-155X+85X^2$ (Germany); and $Y_X=7410+190X+30X^2$ (Australia).

MS Office 2010 was employed for graphical presentation of the data.

3. Results and discussion

The data on the reproductive ability of animals studied are presented in Table 1. The German and American cows had an 8%–15% higher breeding efficiency in the first estrus and a higher index of insemination. The Danish and Australian cows had longer first service periods than the American and German cows. The calf crop from the cows from the USA, Denmark, Germany, and Australia was 87%, 82%, 84%, and 83%, respectively. The BW of the calves at birth ranged from 37.5 to 39.8 kg on average, which corresponds to the parameters for Holstein cattle. The calves obtained from the German cows had better BW parameters by 1.6 kg (ns), 2.3 kg (P < 0.05), and 1.8 kg (ns) than the calves from the American, Danish, and Australian cows, respectively.

Evaluation of the growth and the development of the Holstein cows of various genetic selections revealed that the BW of the German heifers was greater than that of the American, Danish, and Australian heifers (Figure 1).

Under the same feeding and housing conditions, the German heifers were superior in growth rate. Their BW was higher in all age periods, and by 36 months of age it reached 635.0 kg, which was greater than the American heifers by 27.6 kg or 4.5% (P < 0.001); greater than the Danish heifers by 36.5 kg or 6.1% (P < 0.001; and greater than the Australian heifers by 12.2 kg or 2.0% (P < 0.01). The analysis of the BW dynamics of the cows leads to the conclusion that German and Australian Holsteins were notable for their higher rate of growth compared to the American and Danish Holsteins.

Hematological status indicates the resistance level of animals in adapting to new climatic conditions (9,10). Higher erythrocyte, total protein, and phagocytosis indices in the blood serum of the cows from Denmark and Australia indicated specific homeostasis features in the period of adaptation (Table 2). The first-calf heifers imported from the USA and Germany had high concentrations of phagocytic activity to decrease compared with the animals in other groups, indicating the

Table 1. Reproductive ability of heifers of different selections (mean ± SE).

Indices	USA (n = 245)	Denmark (n = 245)	Germany (n = 386)	Australia (n = 250)
Age of the first successful insemination, months	16.2	16.5	17.0	17.3
Body weight at the first breeding, kg	420.5 ± 5.2^{a}	402.0 ± 3.8^{a}	452.0 ± 4.8	418.0 ± 3.0^{a}
The first open period, days	117.2 ± 4.3^{ns}	129.0 ± 3.1^{ns}	125.6 ± 2.9	127.4 ± 4.4^{ns}
Conception rate	1.7	1.8	1.7	1.8
Gestation time, days	286.7 ± 5.1^{ns}	283.5 ± 4.2^{ns}	285.8 ± 5.2	287.2 ± 4.9^{ns}
Age of the first calving cows, days	779.0 ± 9.5^{ns}	783.2 ± 19.4^{ns}	792.5 ± 8.8	799.2 ± 11.0^{ns}
Body weight of calves at birth, kg	38.2 ± 1.2^{ns}	37.5 ± 0.9^{b}	39.8 ± 0.6	38.0 ± 1.1^{ns}
Calves obtained, heads	213	202	325	208

a = P < 0.001, b = P < 0.05 compared to data on the reproductive ability of German cows; ns = not significant.

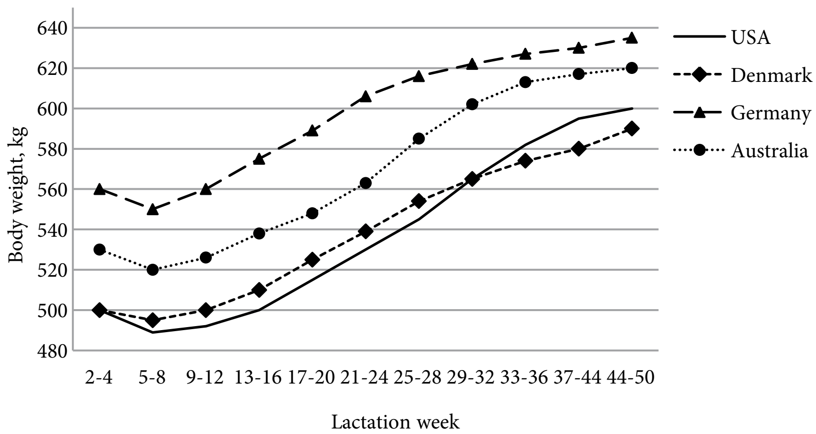

Figure 1. Dynamics of body weight of cows of different selections.

Table 2. Hematological parameters and natural resistance of cows of different selections for the first lactation period (mean ± SE).

Indices	USA (n = 245)	Denmark (n = 245)	Germany (n = 386)	Australia (n = 250)
Hemoglobin, g/L	131.5 ± 4.3[ns]	115.1 ± 2.9[a]	129.6 ± 2.1	113.1 ± 2.4[a]
Erythrocytes, 10^{12}/L	63.5 ± 3.5[ns]	68.1 ± 2.8[ns]	65.7 ± 4.3	69.9 ± 2.4[ns]
Total protein, g/L	84.0 ± 1.5[ns]	90.6 ± 2.1[ns]	86.2 ± 3.0	92.0 ± 1.9[ns]
ESR, mm/h	0.90 ± 0.05[c]	0.54 ± 0.05[a]	1.09 ± 0.06	0.49 ± 0.08[a]
Alkali reserve, mg%	535.3 ± 9.3[c]	551.0 ± 7.2[ns]	561.5 ± 6.5	556.0 ± 8.1[ns]
Leukocytes, 10^9/L	7.21 ± 0.41[ns]	7.82 ± 0.45[ns]	7.29 ± 0.36	7.49 ± 0.32[ns]
Germicidal activity,%	77.1 ± 1.9[b]	65.3 ± 2.0[ns]	69.2 ± 2.2	64.3 ± 2.1[ns]
Lysozyme activity, %	13.7 ± 1.5[ns]	12.9 ± 1.0[ns]	14.8 ± 0.9	12.8 ± 1.2[ns]
Phagocytic activity, %	59.9 ± 2.3[ns]	61.5 ± 5.0[ns]	59.2 ± 2.0	60.0 ± 3.5[ns]
Phagocytic index	11.7 ± 1.1[ns]	14.8 ± 1.1[ns]	12.5 ± 1.0	12.6 ±0.7[ns]
Granulopectic index	5.8 ± 0.6[ns]	6.5 ± 0.8[ns]	6.4 ± 0.3	6.8 ± 1.0[ns]

ESR = Erythrocyte sedimentation rate; a = $P < 0.001$, b = $P < 0.01$, c = $P < 0.05$ compared with data on hematological parameters and natural resistance of German cows; ns = not significant.

superiority of humoral factors of immunity in animals of these selections. It should be noted that the changes in the indices were within the physiological standards.

Milk yields for three lactations were in the range of 23,666–25,220 kg. American cows had maximum milk productivity (25,220 kg), which was more than the milk yield from the Danish, German, and Australian cows by 1554 kg ($P < 0.001$), 360 kg (ns), and 1430 kg ($P < 0.01$), respectively (Table 3). The fat content in milk of all animals appeared to be high (not less than 3.9%); this value increased by an average of 0.1% by the third lactation. The maximum fat content was found in milk of the American and German cows. By the third lactation, this index in their milk was higher than in milk from the Danish cows by 0.1% ($P < 0.05$) and from the Australian cows by 0.05% (ns).

The Australian cows produced the largest amount of protein in milk, followed by the cows from the USA and Germany, which had similar indices (Table 4). The maximum difference in this indicator is fixed between the cows from Australia and Denmark: the milk from the Australian cows contained more protein than the milk from the Danish ones by 0.18% ($P < 0.001$). Analysis of the protein composition of milk from the cows imported from different countries showed that total nitrogen content was higher in milk from the Australian cows than in milk from the American, Danish, and German cows by 0.013% (ns), 0.028% ($P < 0.01$), and 0.016% ($P < 0.05$), respectively. Similar trends were noted in respect to the total count of essential amino acids: the rate was also higher in milk from the Australian cows (Table 5). The smallest amount of essential amino acids was observed in milk from the

Table 3. Dairy-producing ability of cows of different selections (mean ± SE).

Indices	USA (n = 245)	Denmark (n = 245)	Germany (n = 386)	Australia (n = 250)
First lactation				
Milk yield, kg	8200.0 ± 110.5	7600.0 ± 106.0^{a}	8130.0 ± 113.0^{ns}	7630.5 ± 103.5^{a}
Fat content in milk, %	3.95 ± 0.02	3.92 ± 0.05^{ns}	4.00 ± 0.05^{ns}	3.91 ± 0.02^{ns}
Second lactation				
Milk yield, kg	8420.0 ± 114.0	7666.5 ± 111.5^{a}	8230.5 ± 109.3^{ns}	7910.0 ± 105.5^{b}
Fat content in milk, %	4.10 ± 0.02	4.00 ± 0.04^{c}	4.10 ± 0.03^{ns}	3.95 ± 0.02^{a}
Third lactation				
Milk yield, kg	8600.0 ± 110.0	8400.0 ± 104.0^{ns}	8500.0 ± 109.0^{ns}	8250.0 ± 108.0^{c}
Fat content in milk, %	4.10 ± 0.04	4.00 ± 0.02^{a}	4.10 ± 0.02^{ns}	4.05 ± 0.04^{b}
Total milk yield, kg	25220 ± 334.5	23666.5 ± 321.5^{a}	24860.5 ± 331.3^{ns}	23790.5 ± 317.0^{b}

a = P < 0.001, b = P < 0.01, c = P < 0.05 compared with data on the dairy-producing ability of American cows; ns = not significant.

Table 4. Total protein and nitrogen content of raw milk from cows of different selections (mean ± SE).

Indices	USA (n = 245)	Denmark (n = 245)	Germany (n = 386)	Australia (n = 250)
Total protein content*, %	3.38 ± 0.05^{ns}	3.29 ± 0.04	3.37 ± 0.05^{ns}	3.47 ± 0.03^{a}
Total nitrogen content**, %	0.531 ± 0.008^{ns}	0.516 ± 0.007^{b}	0.528 ± 0.006^{c}	0.544 ± 0.005

a = P < 0.001; b = P < 0.01; c = P < 0.05; ns = not significant.
*Compared with data on total protein and nitrogen content of milk from Danish cows.
**Compared with data on total protein and nitrogen content of milk from Australian cows.

Table 5. Amino acid content of raw milk from cows of different selections (mean ± SE).

Indices	USA (n = 245)	Denmark (n = 245)	Germany (n = 386)	Australia (n = 250)
Aspartic acid	220.5 ± 0.7^{c}	219.7 ± 0.7^{b}	222.8 ± 0.8	226.3 ± 1.0^{b}
Glutamic acid	735.2 ± 0.5^{ns}	734.4 ± 0.5^{b}	736.0 ± 0.6	739.7 ± 0.8^{a}
Threonine	148.8 ± 0.5^{c}	148.0 ± 0.6^{ns}	147.5 ± 0.4	146.5 ± 0.7^{ns}
Glycine	48.0 ± 0.4^{ns}	49.1 ± 0.9^{ns}	48.6 ± 0.6	49.9 ± 0.8^{ns}
Arginine	127.0 ± 0.6^{c}	124.0 ± 0.4^{a}	129.0 ± 0.8	131.0 ± 0.6^{c}
Valine	183.0 ± 0.6^{ns}	180.8 ± 0.7^{ns}	181.6 ± 0.9	184.0 ± 0.6^{c}
Methionine	86.5 ± 0.7^{ns}	85.9 ± 0.5^{ns}	87.2 ± 0.7	88.2 ± 0.6^{ns}
Leucine	319.8 ± 0.9^{b}	318.7 ± 0.8^{c}	316.5 ± 0.7	321.3 ± 0.8^{a}
Isoleucine	182.6 ± 0.6^{ns}	182.0 ± 0.4^{ns}	181.0 ± 0.6	184.5 ± 0.8^{a}
Phenylalanine	185.8 ± 0.8^{ns}	183.9 ± 0.6^{ns}	184.2 ± 0.6	186.3 ± 0.7^{c}
Cystine	28.7 ± 0.3^{ns}	29.2 ± 0.4^{ns}	28.8 ± 0.3	29.9 ± 0.5^{ns}
Lysine	256.0 ± 0.5^{c}	255.0 ± 0.6^{ns}	253.9 ± 0.7	257.5 ± 0.5^{a}
Histidine	90.5 ± 0.6^{ns}	89.1 ± 0.8^{c}	91.3 ± 0.6	91.6 ± 0.4^{ns}
Tyrosine	188.5 ± 0.5^{ns}	186.0 ± 0.9^{ns}	187.9 ± 0.8	190.4 ± 0.6^{c}
Tryptophan	48.6 ± 0.8^{b}	49.0 ± 0.9^{b}	45.7 ± 0.6	49.7 ± 0.9^{a}
Total count of essential amino acids	1411.1 ± 4.9^{c}	1403.3 ± 4.0^{ns}	1397.6 ± 4.2	1418.0 ± 4.4^{a}

a = P < 0.001, b = P < 0.01, c = P < 0.05 compared with data on amino acid content in milk from German cows; ns = not significant.

German cows. Their essential amino acid content was less than in the milk from the cows from the USA, Australia, and Denmark by 13.5 mg/100 g (P < 0.05), 5.7 mg/100 g (ns), and 20.4 mg/100 g (P < 0.001), respectively.

Regression analysis showed that the milk yields of the first 5 lactations of the heifers of all genotypes had a parabolic relationship (Figure 2). The Danish cows had the highest milk yield by the fifth lactation (11,872 kg), while the lowest yield was typical for the American cows (8840 kg). The expected milk yields from the German and Australian cows were 9550 and 9110 kg, respectively. Thus, predictions based on mathematical modeling revealed that in long-term economic use, by the fourth lactation the milk yields from the Danish Holsteins would be significantly (8.8%–11.7%) superior to the milk yields from the American, German, and Australian cows. By the fifth lactation this difference would tend to widen to 19.5%–25.5%. We also found that there is a close relationship between milk yield and BW in Holsteins, as well as between BW and milk fat content. The Danish, German, and Australian cows had a positive correlation between economic and genetic traits within the period of three lactations, with a significant increase in the interdependence of the traits observed by the third lactation. In the first and second lactations, the American heifers showed a negative correlation among the indices that indicate longer acclimatization period, as compared with the other genotypes. The closest and most stable correlation among the traits studied was observed in the Danish Holsteins.

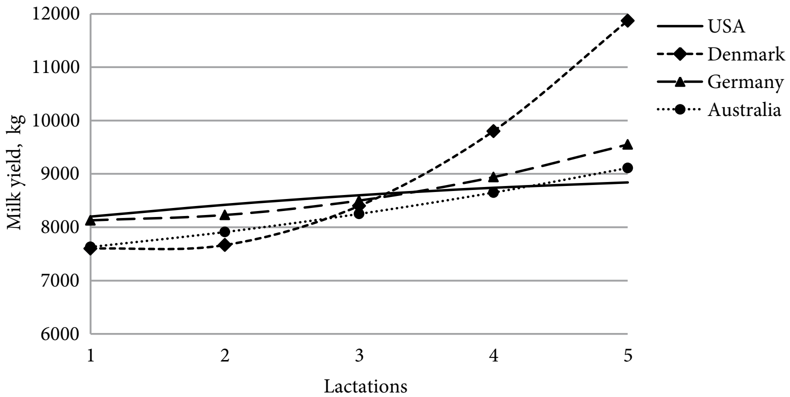

Figure 2. Forecast of milk yields for 305 days of lactation by nonlinear regression equations.

The economic efficiency calculation of production of milk from the Holstein cows (Table 6) shows that the production cost of 1 kg of milk from the cows of the American and German selections was lower by 1.0 ruble (€0.02) on average, and the profitability level was higher by 10.8%–11.3%. The average values were calculated as economic indicators in late 2014, when the RUR/EUR exchange rate was 63.0.

Table 6. Economic production efficiency of milk from first-calf cows. The average values calculated as economic indicators late 2014, the RUR/EUR exchange rate was 63.0.

Indices	USA	Denmark	Germany	Australia
Milk obtained from the first lactation, kg	8200	7600	8130	7630
Milk of standard fat content (3.4%), kg	9526	8762	9565	8775
Cost price of 1 kg of standard fat content milk, €	0.16	0.18	0.16	0.18
Milk sales proceeds, €	2096	1928	2104	1931
Farm inputs, € per head	1556	1556	1556	1556
Market value of milk kg, €	0.22	0.22	0.22	0.22
Profit, €	540	372	548	375
Profitability level, %	34.7	23.9	35.2	24.1

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