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Milk yield of cows in some European countries and the implementation of automatic milking systems

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Abstract. The research study addresses the problem of implementing progress in agricultural production. This problem was developed on the basis of equipping farms with automatic milking systems (AMS). Different forms of progress can be identified on a dairy farm, including technical progress represented by AMS and biological progress expressed by milk yield of cows. The purpose of this research study was to compare whether the milk yield of cows in certain European countries meets the requirements for utilizing the milking potential of automatic milking systems. The study used information on the suggested amount of milk that an one-stall milking robot should milk per year. The second group of data was the annual milk yield of cows in the European Union countries and Great Britain. In eight countries, the annual milk yield of cows was in the range of 8,601–10,600 kg. It was found that in 2020, in these eight countries of the European Union, the milk yield of cows was at a level that meets the performance requirements of one-stall milking robot.

Key words: AMS, annual milk yield, country, cow, robotic milking, progress.

INTRODUCTION

Over the years, progress has been systematically linked to the development of various production areas, including food production (Acevedo, 2011). The growing demand for plant and animal raw materials implies the implementation of more and more modern methods of their production. Production methods in the food economy system are carriers of various forms of progress.

Global progress in agriculture is the result of the continuous search for more and more rational solutions to increase the overall level and efficiency, as well as the sustainability of agricultural production (Dillon et al., 2016). Progress in agriculture, aimed at increasing the efficiency of production, is thus directed at the continuous improvement of facilities in agricultural space.

Technical progress is particularly important for the overall development of agriculture (Michałek & Kowalski, 2000) over the centuries. The creation of simple hand tools, initially wooden and then metal, the construction of more complex agricultural tools and machines adapted to cooperation with live traction, the introduction of steam engines, tractor traction, the construction of self-propelled agricultural machines, robots and the use of satellite techniques are the most significant stages in synthetic description of technical progress identified in the history of agricultural development (Dudin et al., 2014).

Progress in construction usually leads to the creation of more and more modern models of machines and devices that allow to achieve not only higher work efficiency, but also to improve the quality of agricultural operations (Chen et al., 2020). As a result of implementing more and more perfect construction solutions into practice, gradually modifying individual plant and animal production technologies, **technological progress** is being created at the same time. One measure of this progress is the degree of substitution of the work of animals and people with the work of machines and other technical devices. The substitution of human labour in agriculture leads to the gradual automation of processes and changes in the mutual share of human labour and technical equipment (Ianchovichina et al., 2001).

Biological progress, which is an integral part of comprehensively understood progress in agriculture, is currently one of the most dynamic directions of development in scientific research. It leads primarily to the improvement of individual species of plants and animal breeds in order to develop their most beneficial functional features that determine the possible increase in production potential and at the same time meet high quality requirements (Odongo et al., 2010).

Harmonious interaction between particular categories of progress in agriculture is one of the basic conditions for development in many areas of agricultural activity. The relationships between the considered categories of progress are generally synergistic, indicating the possibility of mutually reinforcing the effectiveness of action and thus achieving increasing, primarily economic, efficiency of the process of obtaining high-quality agricultural products.

In the assessment of agricultural production activities, more and more emphasis is placed on sustainable development. The pillars of sustainable development include a set of economic, social and environmental factors (Díaz de Otálora et al., 2021). Sustainable development may also include progress, which is one of the elements stimulating the development of agriculture and its individual sectors. The various forms of progress linked to agricultural production activities give impulse to raising the issue of their sustainable implementation.

Cow milking is one typical example of an area where different forms of progress can be assessed (Gaworski, 2021). The automatic milking system reflects the technical progress that has been made over the past few decades in the field of obtaining milk from cows (Cogato et al., 2021). The production potential of cows in the milk production system identifies biological progress, expressed in the increase in the milk yield of animals. If technical and biological progress in the field of milk production are confronted, a question can be raised regarding the assessment of the effects of the simultaneous implementation of these forms of progress, which determines the sustainable development of the cow milking system on a dairy farm.

The aim of the study was to assess the conditions for the simultaneous implementation of various forms of progress on dairy farms. Equipping dairy farms with automatic milking systems (AMS) was selected as a detailed research area. The research study developed the question of whether the milk yield of cows in certain European countries meets the requirements for utilizing the milking potential of automatic milking systems.

MATERIALS AND METHODS

Milking equipment used on farms differ in the degree of complexity of the design, the level of automation of the tasks performed, efficiency, energy and water consumption per liter of milk and other characteristics (Gaworski et al., 2017). Differences in the achieved efficiency, energy input and manual work for milking determine the possibility of ranking milking systems. In this ranking, according to the value of the technological index level proposed by Nowacki (1999), five generations (G_mI-G_mV) of milking can be distinguished (Table 1). The technological index level is a ratio of machine work inputs to the sum of manual and machine work incurred for individual tasks in production technologies, including agricultural production. The value of the index ranges from 0 to 100%. The lowest values of the technological index level correspond to hand milking, and the highest to the automatic milking system. Translating the scale of the technological index level into milking generations, the lowest values of the index correspond to the first generation of milking (G_mI), and the highest values of the index correspond to the highest generation of milking (G_mV).The transition to ever higher generations of technical solutions identifies technical progress in agricultural production technologies (Nowacki, 1999). The highest level of technical progress in milking is expressed by the highest milking generation (G_mV), and this is represented by the automatic milking system (AMS).

Table 1. Generations of milking cows used on dairy farms, according to Nowacki (1999)

Generation of milking	Solution
G_mI	hand milking
G_mII	bucket milking system
G_mIII	pipeline milking system
G_mIV	milking parlour
G_mV	automatic milking system

The implementation of technical progress represented by milking robots in farms is associated with the assessment of the profitability of their use, justifying the investment in these modern devices. The profitability of using automatic milking systems is the result of many factors, among which the key is the amount of milk milked per year. The results of analyzes presented in the literature indicate that the profitability of using one-stall milking robot is achieved in the case of obtaining 515,000 kg (Meskens et al., 2001), and according to other authors (Heikkilä et al., 2010) 800,000 kg of milk per year. In practice, the one-stall milking robot is usually used in a herd of 50 to 65 dairy cows (Castro et al., 2012; Tremblay et al., 2016). Based on this data, it is possible to calculate what the annual milk yield of one cow should be in order to meet the requirements related to the profitability of using one-stall milking robot on the farm. The calculation requires the assumption that the cows in the herd are subject to rotation related to drying off and calving, therefore the number of cows in the herd operated by the milking robot increases by 15%. Dividing the annual amount of milk to be milked by the size of the herd shows that the milk yield of cows in a barn with one-stall milking robot should be in the range of approx. 8,950 to 10,700 kg of milk per cow per year.

Another approach can also be demonstrated to determine the milk yield range of cows for use in milking robot analysis. Statistical data can be included in this case. Such data, covering the milk yield of cows in geographical regions of the world in 2020, are summarized in Table 2.

The continental data in Table 2 are listed from lowest to highest milk yield of cows. It can be seen that the difference between the lowest and the highest yield is about 10,000 kg of milk per cow per year. This range has been divided into five equal ranges (categories). Value ranges are listed in Table 3.

The highest cow milk yield category ($C_{my}V$) ranges from 8,601 to 10,600 kg of milk per cow per year. This range is close to the calculated yields of cows (8,950–10,700 kg year^{-1}) resulting from the analysis of the profitability of using an one-stall milking robot.

Table 2. Annual milk yield per cow in geographical regions in 2020

Geographical region	Annual milk yield per cow (kg year^{-1})
Africa	595
Asia	1,919
South America	2,446
Oceania	4,887
Australia and New Zealand	4,922
Europe	6,667
North America	10,712
World	*2,678*

Source: www.fao.org/faostat/ [access: 01.09.2022].

Table 3. Categories (C_{my}) of annual milk yield per cow, in (kg year^{-1})

Category	$C_{my}I$	$C_{my}II$	$C_{my}III$	$C_{my}IV$	$C_{my}V$
Range	601–2,600	2,601–4,600	4,601–6,600	6,601–8,600	8,601–10,600
Average value in the range	1,600	3,600	5,600	7,600	9,600

Considering the ranges of milk yield for $C_{my}I$-$C_{my}V$ categories, the question can be raised in which countries the level of milk yield of cows in the highest $C_{my}V$ category has already been achieved. Thus, the question is in which countries the convergence of the highest level of technical progress, i.e. the highest generation of milking (G_mV) represented by milking robots, with the highest level of biological progress, represented by the milk yield of cows (identified by the $C_{my}V$ category), has been achieved. The answer to this question is the content of the research results, which have been extended by additional comparisons and discussion.

RESULTS AND DISCUSSION

The assessment of the conditions for the simultaneous implementation of two forms of progress in the area of dairy production was carried out on the example of data from European countries. Based on data from the European Union countries and Great Britain, Table 4 summarizes the milk yield of cows with assignment to the appropriate $C_{my}I$-$C_{my}V$ category of annual milk yield per cow.

The data in Table 4 show that in eight countries of the European Union, the milk yield of cows in the highest $C_{my}V$ category has already been achieved. In these countries, a convergence of technical and biological progress can be indicated in the case of milk production on farms using milking robots. The considered convergence of two forms of progress (technical and biological) in the area of milking concerns the highest, fifth level of progress: $G_mV \leftrightarrow C_{my}V$. Technical progress in the area of milking cows, identified by equipping farms with automatic milking systems, can be fully used as a result of working with herds of cows included in the highest category of milk yield, representing biological progress. Among the countries with the highest milk yield of cows, in the C_{my}V category, there are four countries located in the Baltic Sea zone.

The largest group of countries is in the fourth category of milk yield of cows - C_{my}IV (Table 4). These are 14 countries where the milk yield of cows is in the range of 6,601–8,600 kg of milk per cow per year. This milk yield category immediately precedes the highest C_{my}V category, important for the efficiency of the milking robots. If we take into account the upward trends in milk production from one cow, the question remains how many countries will soon achieve the milk yield of cows that justifies equipping farms with an automatic milking system. The situation in the following categories of milk yield of cows can be considered in different ways. Fig. 1 presents a comparison of model milk yields of cows (based on data in Table 3) and average milk yields for a set of countries in individual C_{my}II-C_{my}V categories. Only four categories of milk yield of cows were considered, as no country was included in the first category (C_{my}I).

Table 4. Annual milk yield per cow in the European Union and Great Britain and their classification within C_{my}I-C_{my}V categories, based on 2020 data

Categories of annual milk yield per cow	Country	Milk yield (kg year^{-1})	Reference ranges (kg year^{-1})
C_{my}I			601–2,600
C_{my}II	Romania	3,228	2,601–4,600
	Bulgaria	3,645	
C_{my}III	Croatia	5,418	4,601–6,600
	Ireland	5,880	
	Slovenia	6,357	
	Lithuania	6,389	
C_{my}IV	Italy	6,794	6,601–8,600
	Malta	6,949	
	Poland	6,973	
	Latvia	7,264	
	Austria	7,271	
	France	7,279	
	Cyprus	7,496	
	Slovakia	7,519	
	Greece	7,947	
	Luxembourg	8,249	
	Belgium	8,270	
	Great Britain	8,369	
	Germany	8,457	
	Portugal	8,566	
C_{my}V	Hungary	8,913	8,601–10,600
	Sweden	9,109	
	Czech Republic	9,153	
	Netherlands	9,256	
	Spain	9,382	
	Finland	9,414	
	Denmark	10,028	
	Estonia	10,063	

Source: www.fao.org/faostat/ [access: 01.09.2022].

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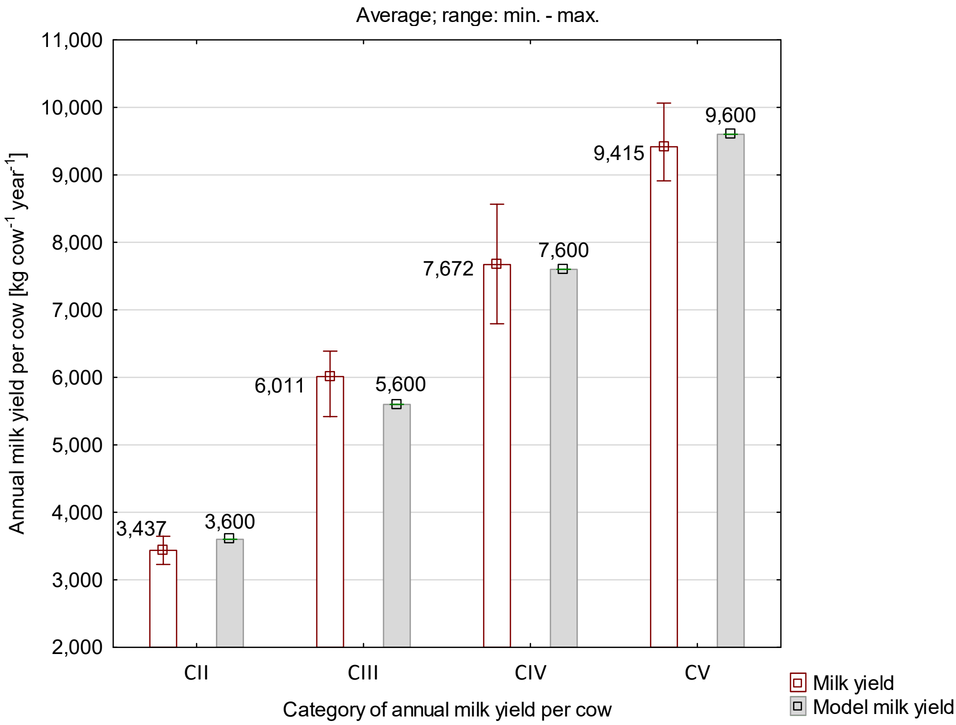

Figure 1. Model milk yields of cows (grey bars) and average milk yields (white bars) for a set of countries in individual C_{my}II-C_{my}V categories.

The greatest differences between the average model milk yield and the average for a given group of countries can be found for category C_{my}III milk yield of cows. In this category, the average milk yield of cows exceeds the model average by more than 400 liters per year (Fig. 1). The smallest difference between the averages is in the C_{my}IV milk yield category. In turn, in this category of milk yield of cows, the largest difference between the minimum and maximum value can be observed, which is more than 1,770 liters of milk per cow per year for the countries in this category. The results presented in Fig. 1 can also be considered in a different way, posing the question: How far are the average milk yields of cows in given categories from the maximum values of the range? That is, how much is missing to move to a higher milk yield category. This issue relates to three categories of cow milk yield. i.e. C_{my}II, C_{my}III and C_{my}IV. Particularly noteworthy is the fourth category of milk yield of cows (C_{my}IV), because it directly precedes the category of milk yield C_{my}V, which with its potential meets the requirements of the milking robot. The difference between the average milk yield of the C_{my}IV category and the maximum bordering on the C_{my}V category is 929 kg of milk per cow per year. Using the average milk yield of cows gives only a general picture of the comparison of the considered C_{my}IV yield category with the C_{my}V category. More valuable information is provided by comparing the milk yield of cows in individual countries of the C_{my}IV category with the maximum yield, which is already exceeded by the C_{my}V category. In this context, the question was raised: By what percentage would it be necessary to increase the milk yield of cows in individual countries to achieve a yield of 8,601 kg of milk per cow per year, which is the minimum for the $C_{my}V$ category of milk yield of cows. The answer to this question is shown in Fig. 2.

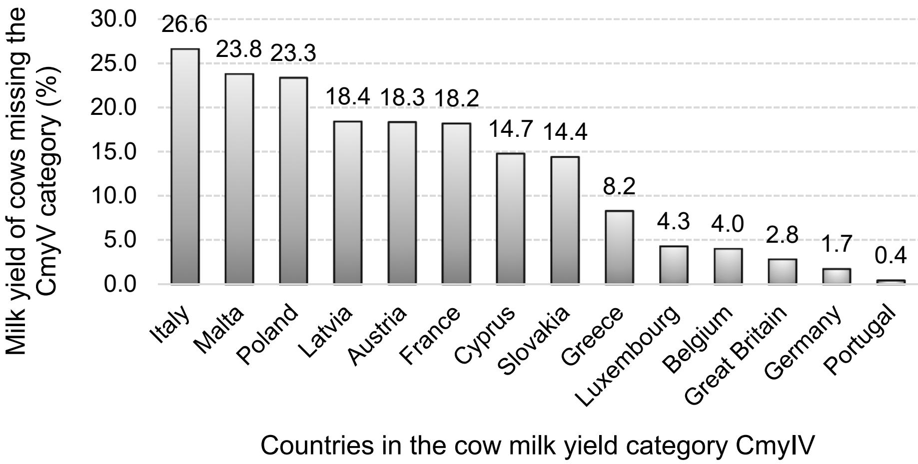

Figure 2. Missing milk yield of cows (in %) needed to achieve the minimum milk yield in the $C_{my}V$ category, by country for 2020 data.

The comparison of the data (calculation results) in Fig. 2 indicates the possibility of distinguishing two groups of countries, with the missing milk yield of cows up to 10% and above 10%. The first group includes six countries where achieving a yield of 8,601 kg of milk per cow per year would require an increase in current yield by 0.4% to 8.2%. In the second group, however, there are 8 countries with a much larger range, from 14.4% to 26.6% of the missing milk yield of cows. These are the results of the calculations for 2020, which can be verified taking into account the data in the following years. In general, the milk yield of cows shows an upward trend every year. Therefore, the number of countries in the distinguished milk yield categories may change, as well as the distance that individual countries have to cover to achieve maximum yield in a given category (C_{my}).

Regardless of the results of the comparison, this research study inspires further discussion on various aspects of improving dairy production at the farm level. Evaluation of dairy production and its improvement on a farm can be considered in the area of milk yield of cows and factors that determine this yield. The milk yield of the cows represents their biological potential, analyzed in this study in conjunction with the technical potential of the milking equipment. In practice, the technical potential does not only apply to automatic milking systems, but also to other milking systems. Gaworski et al. (2018) compared the production and other (health) indices of herds of dairy cows milked with pipeline milking systems, in milking parlours and with the use of milking robots (AMS). The milk yield of cows on farms equipped with AMS was about 24% higher compared to the milk yield of cows on farms with pipeline milking machines. Similar relationships between the productivity of a dairy cow herd and the type of milking system were indicated by Gygax et al. (2007), who compared the use of milking robots and parlours (auto-tandem type) on farms.

The links between milking equipment and the factors that determine milk production on a farm, including cow milk yield and herd size, are the subject of evaluation and optimization of milking on many farms (Gaworski et al., 2017). Such studies, but also those using stochastic models (Nitzan et al., 2006) and other mathematical simulation models (Komiya et al., 2002), have made it possible to evaluate the performance of the milking robot and other milking systems. Research on the efficiency of milking robots (Priekulis & Laurs, 2012) translates into estimation of the effectiveness of their use (Castro et al., 2012), where the production potential of a dairy cow herd is important. The effectiveness of the use of automatic milking systems on farms is also determined by other factors, including those related to the management of a robot-milked herd (Bach et al., 2009; Gaworski et al., 2016). Therefore, the production potential of a herd of dairy cows considered in this research study, which justifies the implementation of a milking robot on a farm, needs to be developed with studies of factors that favor and disrupt the full use of the technical potential of AMS. These are studies related to the assessment of the accuracy of the milking robot (Bach & Busto, 2005), milk quality (Hogenboom et al., 2019), the use of milking robots in the pasture (Lyons et al., 2013), as well as the health and welfare of dairy cows milked by a robot (Jacobs & Siegford, 2012), which directly translates into the milk yield of cows.

The milk yield of cows in robot-milked herds is of particular concern. And this is due to the possible increase in milk yield of cows, which is one of the most important benefits of milking a herd of animals with a milking robot (Tremblay et al., 2016; Filho et al., 2020). Increasing the milk yield of cows milked with a robot is the effect of increasing the frequency of their milking during the day. Milking frequency is taken into account in many studies of automatic milking systems, with for example 2.47 milkings per day (Gygax et al., 2007), 2.5 milkings per day in multiparous cows and 2.8 milkings per day in primiparous cows (Speroni et al., 2006). An important issue is also the frequency of milking cows with an automatic milking system combined with grazing (Lessire et al., 2020). In the majority of farms with conventional milking systems, cows are milked twice a day, hence the milk yields achieved there are a comparative basis for cows in robot-milked herds (Hansen et al., 2019). Considerations regarding the frequency of milking per day and the resulting milk yield of cows are an important contribution to the discussion of the results presented in Fig. 2. For some countries with milk yields in the C_{my}IV category, the missing yield from the C_{my}V category can be achieved by increasing the frequency of milking. It follows that it can be proposed to equip some farms with a herd of cows with a productivity in the C_{my}IV category with a milking robot, which will increase the milk yield of cows and their transition to the C_{my}V category. The question is how much of an increase in cow milk yield can be expected as a result of the transition from conventional to robotic milking. In response to this problem, the studies presented in the literature indicate the possibility of increasing the milk yield of cows with the increase in the frequency of milking from 2 to 3 times a day. For example, Erdman & Varner (1995) found an increase in milk yield of primiparous cows by 17.65% and multiparous cows by 18.32% when switching from 2 to 3 milkings per day.

In addition to the milk yield of cows, the size of the herd is a key factor in ensuring the appropriate production potential of a robot-milked herd. In this research study, the size of the herd of dairy cows was taken into account at the first stage of considerations regarding the determination of the range of milk yield of cows in a herd milked with an automatic milking system (AMS). The second stage of considerations was developed on the basis of data on milk yields of cows in a group of 27 countries of the European Union and Great Britain. Of course, each country is distinguished by the average size of dairy herds on farms and the structure of herds in terms of their size. This aspect of the analysis, already taken up in earlier comparative studies (Leola et al., 2021), can be a direction for further research included in the analysis of the simultaneous implementation of various forms of progress in dairy production on farms.

The presented problem of simultaneous implementation of various forms of progress on the example of milking robots is part of the direction of research devoted to the assessment and comparison of the potential of dairy production in Europe (Gaworski & Leola, 2015) and other regions of the world (Matson et al., 2021). Proposals of indicators and research tools, such as decision trees (Piwczyński et al., 2020), deep learning (Liseune et al., 2021), optimization models (Zhang et al., 2016) and management models with a decision support system (Gargiulo et al., 2022) are used to plan dairy production now and in the future, which is a premise for the sustainable development and ethical transformation (Gaworski, 2006) of the food economy system.

CONCLUSIONS

The implementation of technical progress in agriculture may generate high costs, which in the case of one-stall milking robots usually exceed 100,000 euro (at the beginning of this decade in Poland). That is why it is so important to fully use the technical potential of agricultural equipment. This may be facilitated by a balanced approach to linking technical progress with biological progress and other forms of progress that are part of the improvement of production processes in agriculture.

This research study showed significant differences in the conditions for the implementation of technical progress, i.e. milking robots, in individual regions of Europe. In 2020, in eight countries of the European Union, the average milk yield of cows was achieved that meets the criteria for their inclusion in the automatic milking system. Increasing the milk yield of cows is a continuous process and as a result, in a growing number of countries, the conditions are being created for the cost-effective implementation of technical progress in the field of milking cows.

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