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原　著

Changes of the milking and visiting frequency with the number of cows kept in an automatic milking system

Shigeru MORITA, Yuki SUTO and Encheng LIU
College of Agriculture, Food and Environment Sciences, Rakuno Gakuen University, Ebetsu, Hokkaido 069-8501，Japan

Corresponding author：Shigeru MORITA
College of Agriculture, Food and Environment Sciences, Rakuno Gakuen University
582，Bunkyodai-Midorimachi, Ebetsu, Hokkaido 069-8501，Japan
Tel：011-388-4756，Fax：011-387-5848
E-mail：smorita@rakuno.ac.jp

群飼養頭数に伴う乳牛の自動搾乳機への訪問回数および搾乳回数の変化

森田　茂・須藤　由貴・劉　恩呈
酪農学園大学農食環境学群　北海道江別市 069-8501

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Summary

The automatic milking system（AMS）was based on a cow's voluntary visits to the milking unit(s). The objective of this study was to describe changes of the milking and visiting frequency with the number of cows in a commercial AMS farm. Six investigations were completed in a commercial dairy farm that used an automatic milking system. Two automatic milking machines（Milking units, MU）were installed in the barn. The partial mixed ration（PMR）was fed once a day, and two types of concentrates were offered in the automatic milking units. The individual milk yield and number of visit to the automatic milking units were calculated. The total milk production was highest（4, 703kg/day）at the investigation period with 115. 8 cows, and lowest（3, 676kg/day）at the period with 90. 7 cows. The total number of milking increased with the number of cows linearly. A significant（P<0. 05）equation was given from the relationship between the total milking frequency（y, times/day）and the number of cows（x）: y = 1. 86x + 122. 40 [1]. This equation showed that milking times increased with the number of cows. A significant（P<0. 05）equation was given from the relationship between the total visiting frequency（y, times/day）and the number of cows（x）except with the 90. 7 cow investigation: y = −2. 66x + 762. 45 [2]. An intersection of the two equations [1] and [2] was given with 141 cows by extrapolating two equations. It was theoretically estimated that the milking times was 386 with this situation. A significant（P<0. 05）equation was given from the relationship between the milking frequency per cow（y, times/day）and the number of cows（x）: y = −0. 020x + 5. 14 [3]. A significant（P<0. 05）equation was given from the relationship between the visiting frequency per cow（y, times/day）and the number of cow（x）: y = −0. 064x + 11. 37 [4]. An intersection of the two equation [3] and [4] was given at around 140 cows. We concluded that 109-cows per 2-milking units was the actual limitation of the AMS to work, smoothly, i.e. fewer cow fetched for milking and a better life of the cows in the AM system.

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要　約

本研究では、群飼養頭数が乳牛の自動搾乳機への訪問および搾乳回数に及ぼす影響を検討した。牛舎は自

由往来型で、１群の乳牛群に２台の自動搾乳機を設置した農場１戸を調査対象とした。調査期間は2017年８月から2018年９月で、１期１週間分の自動搾乳機訪問、搾乳および通過（搾乳されずに退出）に関するデータを期間中６期、採取した。期間中の飼養頭数は、91～116頭であった。結果および考察自動搾乳機２台での総搾乳量は、91頭時の3,676kg/日から116頭時の4,703kg/日の範囲にあり、飼養頭数の増加とともに直線的に増加した。飼養頭数の増加に伴い総搾乳回数は、91頭時の286回/日から116頭時の336回/日へと直線的に増加した。飼養頭数と総搾乳回数（回/日）の間に、y = 1.86x + 122という回帰式が得られた。91頭時を除く乳牛群で、飼養頭数と総訪問回数（回/日）の間に、y=−2.66x+762という直線回帰式が得られた。両関係から141頭時に386回で理論的な自動搾乳機利用の限界に達すると推測した。１頭当たりの訪問回数は、飼養頭数の増加に伴い直線的に減少した。１頭当たりの搾乳回数(y)は飼養頭数(x)との間に、102頭以上の牛群で、y＝−0.020x+5.14という回帰式が得られた。両関係から140頭時に通過回数はゼロとなり、自由往来型における飼養頭数の理論的限界が推定された。自動搾乳システムの円滑な運営には、109頭付近での使用が適切と考えた。

Introduction

The automatic milking system（AMS）was based on a cow's voluntary visits to the milking unit(s). This is one of the characteristics of the AMS system versus the parlor milking system（conventional system）. In this aspect, when to visit the milking unit was one option in the life of a cow in an AMS system.

Milking frequency was affected by the locomotion characteristics of cows and the amount of the concentrate intake in a milking unit（Cordova *et al*., 2018）. Morita *et al*.（2017）surveyed 30 Japanese dairy farms that used an AMS, and they pointed out that the daily milking frequency was related to the daily milk production（i.e. sales volume of milk from the farm）, strongly and positively.

For increasing the milk production in a commercial farm, it was necessary that the level of milk yield per cow and/or the number of cows kept in the system was increased. Increasing the number of cows in the barn is easier for farmers because the feeding amount of the partial mixed ration（PMR）have to change, but the composition of the PMR does not have to change. On the other hand, sometimes, adaptation from increasing the number of cows is difficult for the dairy cows in the barn.

Morita *et al*.（2016）concluded that a quadratic equation was given to describe the relationship between the frequency of visiting the AM unit and the number of cows. From this equation, the visiting frequency decreased with over 41 cows. They discussed that this decrement might be caused by the social interactions of cows at the entrance of the milking unit. Social hierarchy influenced cow's visits to the milking unit（Ketelaal-de Lauwere *et al*., 1996; Morita *et al*., 1996）, such as the waiting time for entering the milking unit（Melin *et al*., 2006）.

The objective of this study was to describe changes of the milking and visiting frequency with the number of cows in a commercial AMS farm, and to show the theoretical limitation of the number of cows in an AMS barn.

Material and Methods

Six investigations（with seven days of data in one investigation）were completed in a commercial dairy farm that used an automatic milking system from August, 2017 to September, 2018. The maximum number of cows was 116 and the minimum number of cows was 91 in six investigations（Table 1）. Two automatic milking machines（Milking units, MU）were installed in the barn. The partial mixed ration（Dry matter（DM）44.3%、TDN 72.1% and CP13.2%）was fed once a day at around 10:00, and two types of concentrates（Concentrate A: DM 88.0%、TDN 84.1%、CP18.2%、and Concentrate B:DM 88.0%、TDN 85.2%、CP 26.1%）were offered in the automatic milking units depending on their milk yield.

The daily amount of offering in the milking unit per cow was from 5.5 to 6.3kg/cow. The average parity of cows ranged from 2.0 to 2.3, and average days of milking was from 160 to 192 days（Table 1）. The records of the automatic milking unit were made with a backup, and the individual milk yield and number of visit to the automatic

Table 1. The average number of cows, parity, days in milking and the amount of concentrate offering in several invetigation period.

Backup Year-Month	Aug-17	Sep-17	Dec-17	May-18	Aug-18	Sep-18
Number of cows	109.0 ± 3.6	112.1 ± 5.0	102.2 ± 0.5	90.7 ± 3.0	115.8 ± 0.4	105.7 ± 0.5
Parity	2.0 ± 1.0	2.0 ± 1.0	2.1 ± 1.1	2.1 ± 1.2	2.3 ± 1.2	2.2 ± 1.2
Days in milking, day	159.7 ± 111.7	162.8 ± 109.7	185.9 ± 92.2	191.0 ± 110.8	175.4 ± 114.0	192.0 ± 112.4
Concentrate, kg/day	5.5 ± 2.6	5.7 ± 2.6	6.2 ± 2.2	5.5 ± 1.3	5.9 ± 2.2	6.3 ± 2.2

Table 2. Total milk production, total milking frequency and working time for milking in several investigation period.

Backup Year-Month	Aug-17	Sep-17	Dec-17	May-18	Aug-18	Sep-18
Total milk production, kg/day	4388.1^{ad} ± 104.9	4490.8^{a} ± 178.2	4238.8^{d} ± 147.2	3675.5^{b} ± 78.9	4702.8^{c} ± 125.9	4463.2^{ad} ± 100.9
Total frequency of milking, times/day	321.9^{ab} ± 7.1	327.1^{a} ± 23.2	318.3^{ab} ± 11.2	285.7^{b} ± 28.3	335.7^{a} ± 39.7	333.1^{a} ± 8.9
Machine working time for milking, hours/day	20.2^{a} ± 0.5	20.1^{a} ± 0.9	19.2^{b} ± 0.3	17.8^{c} ± 0.7	21.0^{a} ± 0.7	21.0^{a} ± 0.5

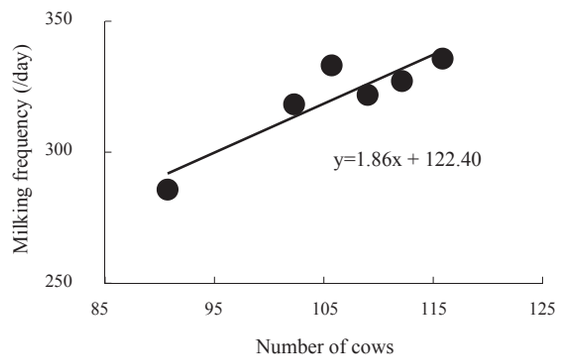

Fig. 1. The relationship between the number of cows and the milking frequency.

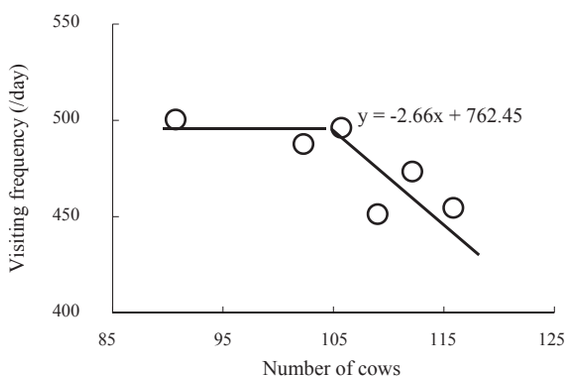

Fig. 2. The relationship between the number of cows and the visiting frequency.

milking units were calculated. The total milk yield, and number of visits per day were taken by summing up the individual data from the six investigations. The average of the number of visits and milking were compared among the investigations.

Data were analyzed using the package of the R version 3. 4. 1. It was used one-way ANOVA and Tukey HDS test for the comparison of the average, and linear regression analysis for testing the relationship between the two items in this study.

Results and Discussion

The total milk production, total milking frequency and the working time of the milking machine were shown in Table 2. The total milk production was highest (4, 703

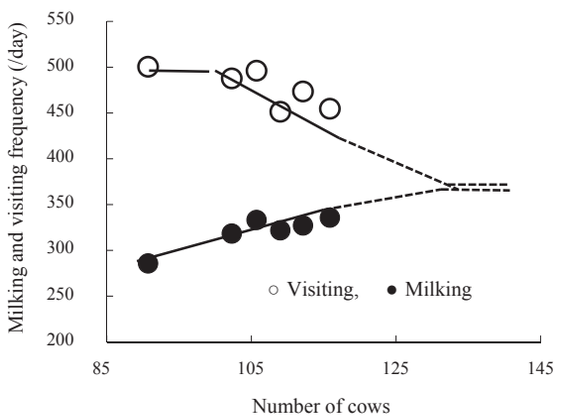

Fig. 3. The estimation of the theoretical limitation of the total number of milking by extrapolating the two equations. The intersection of the equations (no refusal visit) was given at around 141 cows. And 386 milking was estimated at this situation, theoretically.

kg/day) at the investigation period with 115. 8 cows, and lowest (3, 676kg/day) at the period with 90. 7 cows kept in the barn. There was a significant (P<0. 05) positive relationship between the number of cows and the total milk production (r=0. 970, P<0. 05). The total milking frequency was the highest, and the working time of the milking machine was the longest in the period with 115. 8 cows.

The change of the total number of milking in and visiting the automatic milking units with the number of cows in the barn was shown in Figures 1 and 2. The total number of milking increased with the number of cows linearly (Fig. 1). A significant (P<0. 05) equation was given from the relationship between the total milking frequency (y, times/day) and the number of cows (x): y = 1. 86x + 122. 40 [Equation 1]

This equation showed that milking times increased with the number of cows, but only 1. 9 times (under two times/day) with the increase of one cow. Normally, conventional dairy farmer milked twice a day. The increment of the milking frequency was less than two times per day. Even though increasing the number of cows is an easier way for farmers, it might not be beneficial enough for milk production with an AMS system.

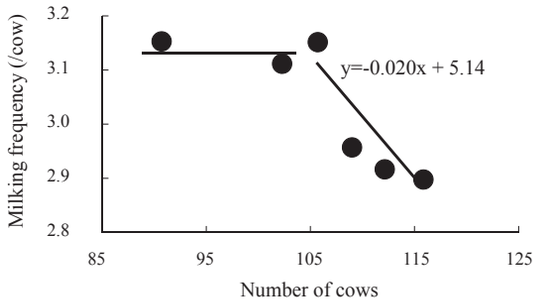

Fig. 4. The relationship between the number of cows and the daily milking frequency per cow.

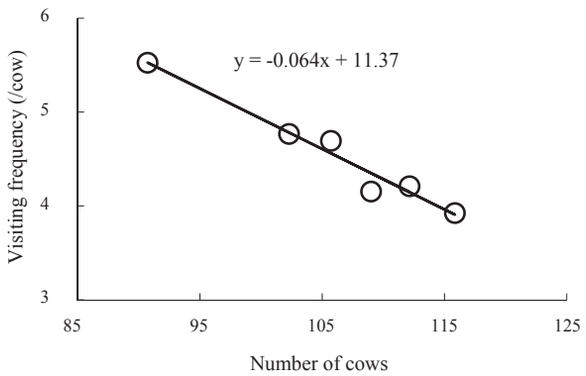

Fig. 5. The relationship between the number of cows and daily visiting frequency per cow.

The total visiting frequency decreased with the number of cows except with the 90. 7 cow investigation (Fig. 2). A significant (P<0. 05) equation was given from the relationship between the total visiting frequency (y, times/day) and the number of cows (x) except with the 90. 7 cow investigation: y = −2. 66x + 762. 45 [Equation 2]

To conclude, increasing the number of cows in an AMS brought about an increase the total milking times and a decrease visiting times to milking units. The automatic milking system was based on a cow's voluntary visits to the milking unit(s). The milking times could not exceed the visiting times. An intersection of the two equations [1] and [2] was given with 141 cows by extrapolating two equations (Fig. 3). It was theoretically estimated that the milking times was 386 with this situation. These levels of the number of cows and milking times per day might be the limitation of the two automatic milking unit system in one cow group as this study.

Changes of the daily milking and visiting frequency per cow with the number of cows were shown in Figures 4 and 5. The daily milking frequency per cow decreased with the number of cows linearly except with the 90. 7 cow investigation (Fig. 4). A significant (P<0. 05) equation was given from the relationship between the milking frequency per cow (y, times/day) and the number of cows

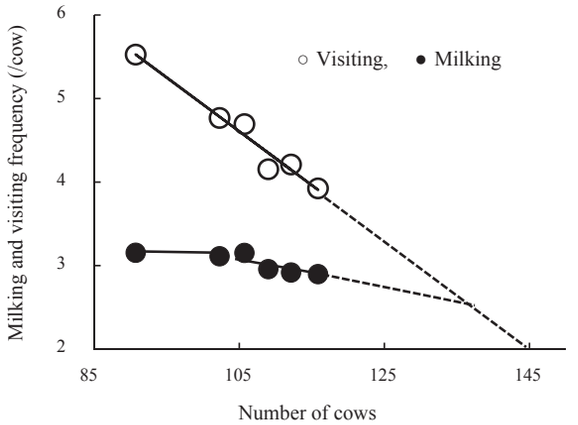

Fig. 6. The estimation of the theoretical limitation of daily milking frequency per cows by extrapolating the two equations. The intersection of the equations (no refusal visit) was given at around 139 cows. At 145 cows, it was estimated that average milking times per cow was two.

(x): y = −0. 020x + 5. 14 [Equation 3]

The daily visiting frequency per cow decreased with the number of cows linearly (Fig. 5). A significant (P<0. 05) equation was given from the relationship between the visiting frequency per cow (y, times/day) and the number of cow (x): y = −0. 064x + 11. 37 [Equation 4]

These equations (Equations 3 and 4) show the frequency of milking and visiting decreased with a higher number of cows kept in the barn. The correlation coefficient of [Equation 4] was larger than that of [Equation 3]. The difference between the frequency of visiting and milking was refusal to visit. The refusal to visit is a negative factor for machine use, but also a sign of the margin of the use of the milking unit by the cows. The automatic milking system was based on the cow's voluntary visits to the milking unit(s). A cow's visit is based on the motivation level and congestion at the entrance of the milking unit. To keep a cow's good quality of life in an AMS barn, their will to visit should be obtained.

An intersection of the two equation [3] and [4] was given at around 140 cows (Fig. 6). There was some refusal to visit on a free-cow-traffic AM system. There was no refusal to visit over this number of cows (140 cows), this number of cows is the limit of the AM system to work well. And it was estimated that average milking times per cow was two when the number of cows was 145.

It was empirically recommended that the times of refusal of visiting is half of the milking times for the AMS to work more effectivity. On this recommendation, the difference between [equation 3] and [equation 4] was equal to the half of [equation 3]. The number of cows in this situation was

around 109 cows by according to the equations.

One of the farmer's aims for the introduction of an AMS is the reduction of labor, and another aim is to focus on the increase of milk production via an increase of milking frequency. When the farmer would like to select latter aim, the farmer tended to keep more cows in AMS barn. Lee *et al*. (2019) described that total milk production per a milking machine increased with the number of cows. In this situation, the number of cows who could not enter to milking unit themselves might increase. Thus the farmer has to fetch the cows who have long intervals for milking. This went against labor saving.

We concluded that 109-cows per 2 milking units was the actual limitation of the AMS to work, smoothly, i.e. fewer cow fetched for milking and a better life of the cows in the AM system. Further studies about the visiting pattern of cows were need for the evaluation of cow's effort to adapt the crowded condition in AMS system.

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