Methodology of Comparing Three Milking Clusters in a Large Dairy Herd

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ABSTRACT

Data for milking parameters were obtained from three different milking clusters using a modified Latin square design to take into account the real milking time regimen of the farm and the time requirements to sort cows. In this modification, cows entered the milking parlor in a random sequence rather than by group. In addition, the clusters were assigned to milking sites. Parameters were compared for 554 cows from one dairy herd that was divided into two smaller herds of 410 and 144 cows. A modified Latin square design was used to compare clusters. The results revealed that 92.1 and 95.5% of cows in Experiments 1 and 2, respectively, were treated by all three clusters; 7.9 and 4.5% of the cows, respectively, were treated by only two clusters; and no cow was treated by only one cluster. The milking parameters for both experiments were in good agreement. Results demonstrated that the modified Latin square design was equivalent to the original Latin square design under the constraint that the number of cows included in one experiment should be >100 and that the number of milkings should not be <200 per cluster. (Key words: methodology, Latin square design, milking clusters)

INTRODUCTION

The essential prerequisite for milking machine comparison involves the minimization of random interferences that can distort the results of measurements. Experimental conditions are close to real conditions if the influences of milking routine, management, and natural environment are the same for all treatments and if the experiments are carried out with a large number of cows. Comparisons within a single large herd rather than within several smaller herds are of particular advantage because various unmanageable interferences of individual farms are considerably reduced or eliminated. The Latin square design widely meets these requirements (3, 6, 7). In accordance with the number of treatments (milking clusters), groups of cows are established. Each group includes the same number of cows and is treated with each of the milking clusters, which are applied daily. The interpretation of comparative results of such tests is bound to specific test conditions, for instance, conditions originating from lowline or highline milking systems. To recognize the differences between milking machines under the same application conditions, this constraint is advantageous.

In the present work, a modified Latin square design was applied to a large dairy herd to obtain milking parameters from three different milking clusters. Results of the modified Latin square design were evaluated by comparing the partition of cows in the modified Latin square design with that of the original Latin square.

MATERIALS AND METHODS

Cows and Equipment

To obtain comparative data for three types of milking clusters, two experimental series were performed in a dairy farm housing approximately 650 cows. A total of 554 cows (1 to 7 mo of lactation) were included and divided into two groups. The first group consisted of 410 cows (first lactation), and the second group consisted of 144 cows (second to eighth lactation); mean daily milking yields were about 15 and 19 kg, respectively. The remaining cows were excluded from the experiments because of their early or late lactation stage.

Housing groups consisted of 36 cows. Cows were milked in two herringbone milking parlors with double-12 sites that were used consecutively. The first lactation cows were treated in one parlor and later lactation cows in the second parlor. In this manner, one milking parlor was always used within one experiment.

Methods

The daily milking time amounted to 8 h in the a.m. and 7 h in the p.m. The high intensity of milking
Table 1. Assignment of three different milking clusters (A, B, and C) according to the original and the modified Latin square design.

<table>
<thead>
<tr>
<th>Milking periods</th>
<th>Original Latin square treatment for cow groups</th>
<th>Modified Latin square treatment for milking sites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1 to 3; a.m., p.m., a.m.</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>4 to 6; p.m., a.m., p.m.</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>7 to 9; a.m., p.m., a.m.</td>
<td>C</td>
<td>A</td>
</tr>
</tbody>
</table>

Figure 1. Variants A, B, and C of milking clusters assigned to groups of front, middle, and rear milking sites in a double-twelve herringbone parlor.
tioned. The number \( k \) of possibilities to allocate \( n \) milkings into \( N \) clusters is given (4) by

\[
k = \frac{(N + n - 1)!}{n!(N - 1)!}.
\]

For the situation in which \( N = 3 \) clusters and \( n = 9 \) milkings, 55 possibilities \( (k) \) exist to partition the 9 milkings of each cow into three treatments. The spectrum of these possibilities ranges from the uniform distribution of 3 milkings per treatment, as with the original Latin square design, to extremely varied distribution with all 9 milkings occurring only within one treatment.

To analyze the distribution obtained, cows were divided into four groups with respect to 55 possible partitions of their individual milkings. Group 1 was characterized by the distribution of individual milkings for the original Latin square design, dividing their 9 milkings into equal parts over the three treatments. Groups 2, 3, and 4 revealed an increasing portion of milkings in favor of one of the treatments. According to the theory (Figure 2), there could be a remarkably large number of possible partitions in groups 3 and 4. These groups were not as favorable for comparison of different clusters as were the other groups. However, the planning of the experiments was based on the idea that a certain number of cows repeatedly prefer to occupy the same or similar positions in the milking parlor. The number of cows with partitions of individual milkings, as shown for groups 3 and 4, decreased as the total number of cows increased, which in turn increased the probability of a balanced distribution of individual milkings relative to the treatments. Furthermore, imbalanced partitions of individual milkings and of a.m. and p.m. milkings were expected to be compensated by a larger number of cows (100 to 400 cows).

To provide evidence for these assumptions, two analogous experimental series with different numbers of cows were established to evaluate the results obtained by using the modified Latin square design. The reliability of results depended on whether the three milking machines were tested with almost all cows and with almost the same percentage of a.m. and p.m. milkings. Only in this case could the advantages of the modified Latin square design be utilized.

**RESULTS AND DISCUSSION**

Only 45 (11.0%) of the 410 cows in Experiment 1 and only 12 (12.6%) of the 144 cows in Experiment 2 had to be excluded because of incomplete data files (<9 milkings per cow), which were caused primarily by changes in housing groups (management) and losses of cow identification, especially in the herd of primiparous cows. Furthermore, 6 primiparous cows were excluded because of low milk yield.

When all milkings for cows that provided 9 milkings (359 cows in Experiment 1 and 132 cows in Experiment 2) were considered, results showed that, for Experiment 1, treatment A included 1075 milkings, treatment B included 1079 milkings, and treatment C included 1077 milkings. For Experiment 2, treatment A included 398 milkings, treatment B included 389 milkings, and treatment C included 401 milkings. This total distribution of milkings was evaluated as being well-balanced. However, the total distribution did not provide information about whether the individual milkings were allocated proportionally to the treatments.

**Partition of Cows and Individual Milkings**

Figure 2 shows the theoretical and real grouping of cows on the basis of individual distribution of milkings with respect to the treatments, revealing that only 10.1% of milkings in Experiment 1 and only 7.6% of milkings (group 1) in Experiment 2 were partitioned according to the original Latin square design, providing 3 milkings in each treatment. About one-half of all cows (52.3% in Experiment 1 and 51.2% in Experiment 2) and ≥2 milkings per treatment (group 2), and one-third of all cows (29.6% in Experiment 1 and 35.6% in Experiment 2) yielded ≥1 milking per treatment (group 3). The results obtained indicate that >90% of the cows (92.0% in Experiment 1 and 94.4% in Experiment 2) were milked with all three milking clusters. Only 7.9% (Experiment 1) and 4.5%
(Experiment 2) of the cows (group 4) did not have any milking in one of the treatments. There was no occurrence of milking by only one kind of cluster.

Compared with the theoretical distribution, the real percentage of cows with a very imbalanced distribution of milkings (group 4) was relatively small. This result supports the assumption that a considerable number of cows preferred to occupy certain areas of the milking parlor. The behavior of groups with >30 cows entering a milking parlor is not extensively documented in the literature. Therefore, an investigation of the preferences for the occupation of the same parlor area was included in the present work. Figure 3 demonstrates the percentage of cows that were milked at least 5 times out of 9 possibilities at front sites (sites 1 to 4), middle sites (sites 5 to 8), or rear sites (sites 9 to 12). Because of the exchange of milking clusters between milking areas, these cows were treated within all variants. Figure 2 also shows that the largest percentage of these cows was in group 1 (69.4 and 70.0% in Experiments 1 and 2, respectively). The percentage of cows decreased as distribution of individual milkings became increasingly unbalanced (group 2 to 4). For both experiments, the relationship was significant (P < 0.05), but the correlation (1) was relatively weak, characterized by a contingency coefficient of 0.22.

The partition of the number of cows (Figure 2) and the frequency of occupying preferred areas in the milking parlor (Figure 3) led us to conclude that there was no rigid order in entering the milking parlor. However, a weak ordering mechanism seemed to exist; in both experiments, approximately 50% of cows were milked in the same parlor area during 56% of the nine milking periods. These results agreed with the results of Arave and Albright (1), who found that the dominance range was stable for cows at either extreme in the group social structure but fluctuated for the range of middominant cows.

Further analyses, including lactation stage, lactation number, and milk yield, revealed similar but nonsignificant signs of a weak ordering with respect to the site in the parlor or the milking behavior of the cows. According to Ferguson (2), the older cows from Experiment 2 had the tendency for higher milk yield at front sites in the parlor. This relationship was not true of first lactation cows (Experiment 1).

**Division of a.m. and p.m. Milkings**

In accordance with the expectation based on a.m. (n = 5) and p.m. (n = 4) milkings in Experiment 1 and a.m. (n = 4) and p.m. (n = 5) milkings in Experiment 2, 55.5% of the milkings occurred in the a.m. in Experiment 1 and 44.4% in Experiment 2, respectively. The deviations of the expected portions in clusters A, B, and C were <1% within each experiment. The order of magnitude of this deviation was examined by calculation, and was found to have no influence on the milking parameters compared (Table 2).

Figure 4 shows all deviations (percentages) from the theoretical distribution of a.m. and p.m. milkings for treatments A, B, and C (Experiment 1 and 2.

![Figure 3](image1.png)

**Figure 3.** Relative number of cows in groups 1 to 4 with at least 5 milkings in one of the three areas of the milking parlor (front, middle, and rear milking sites). Experiment 1 (■) involved 359 primiparous cows; Experiment 2 (□) involved 132 cows. Nine milkings were available per cow. Four groups were established: 1) cows with 5 milkings in each of the variants, 2) cows with only 2 milkings in one of the three variants, 3) cows with only 1 milking in one of the three variants, and 4) cows with only 1 milking in one of the three variants (100% cows per group).

![Figure 4](image2.png)

**Figure 4.** Observed deviations (●; percentage) in favor of a.m. and p.m. milkings relative to the number of milkings that were assigned to variants A, B, and C and groups of individual distributions in both experiments (100% of a.m. and p.m. milkings). Regression equation: \( y = 3.96 \times e^{-0.006x}; \ r = 0.78; \ P < 0.001 \).
within the individual groups 1 to 4). A certain number of cows or milkings is necessary to minimize imbalances between expected and measured percentages of a.m. and p.m. milkings. The deviations were more pronounced in Experiment 2, which used fewer cows (132 cows). The imbalance was considerable when the number of milkings was <200 per treatment.

**Milking Parameters of the Two Experiments**

Mean values for milking parameters that were obtained from the two experiments are shown in Table 3. Almost without exception, both experiments led to the same relationship between the variants of milking machines. The milk flow rate and the total milking time were slightly higher in Experiment 2 than in Experiment 1. These changes were attributed to a generally increased milk yield of the older cows. The only change of the ordering between clusters A and B for the total milking time in Experiment 2 originated from a service arm used for positioning the cluster B on the udders.

Most differences in the milking parameters from both experiments were significant at $P < 0.05$, but some parameters of Experiment 1 (359 cows) were significant at $P < 0.01$.

**CONCLUSIONS**

The good agreement of milking parameters between the two experiments, the fact that in both experiments >90% of the cows were treated with all milking machines, and the well-balanced distribution of a.m. and p.m. milkings indicated that the modified Latin square design is useful for comparisons of the performance of milking units in large herds. The modified Latin square design is more compatible than the original with the operation of commercial farms. The extent of preparation is low, and only the nominal milking time is needed. A boundary condition of the modified design concerns the minimum number of cows. The balanced distribution of cows, of individual milkings, and of a.m. and p.m. milkings with respect to the treatments depends on the number of cows. The deviations from the theoretical expectations increase with a decreasing number of cows and milkings per treatment.

Loss of data originating from cows with <9 milkings (ca. 10%), caused by incorrect identification and disease, led to a minimum of about 200 milkings per variant and to the necessity of >100 cows. However, more milkings were preferable to increase the significance of the results.

For 60% of the cows, distribution of their 9 individual milkings was well-balanced relative to the

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**TABLE 3.** Mean milking parameters for treatments A, B, and C in Experiment 1 (359 cows with a complete data file) and in Experiment 2 (132 cows with a complete data file).

| Parameters per milking | Experiment 1 | | | Experiment 2 | | |
|------------------------|--------------|-----|----------------|--------------|-----|
|                        | A            | B   | C              | A            | B   | C              |
| Milk yield, kg         | 7.41<sup>a</sup> | 7.45<sup>a</sup> | 7.25<sup>b</sup> | 9.50<sup>a</sup> | 9.40<sup>a</sup> | 9.13<sup>b</sup> |
| Milk flow rate, kg/min | 1.26<sup>a</sup> | 1.26<sup>a</sup> | 1.31<sup>b</sup> | 1.32<sup>a</sup> | 1.36<sup>a</sup> | 1.40<sup>b</sup> |
| Machine stripping yield, g | 190<sup>a</sup> | 340<sup>b</sup> | 400<sup>c</sup> | 230<sup>a</sup> | 400<sup>b</sup> | 440<sup>c</sup> |
| Machine stripping time, min | 0.63<sup>a</sup> | 0.93<sup>b</sup> | 0.78<sup>c</sup> | 0.66<sup>a</sup> | 0.88<sup>b</sup> | 0.78<sup>c</sup> |
| Total milking time, min | 6.67<sup>a</sup> | 6.85<sup>b</sup> | 6.31<sup>c</sup> | 8.06<sup>a</sup> | 7.73<sup>b</sup> | 7.37<sup>c</sup> |

<sup>abc</sup>Means within rows with different superscripts differ ($P < 0.05$).
three milking clusters, providing at least 2 milkings per treatment, which reflected only 18% of 55 possible partitions. Only about 10% of all cows distributed individual milkings in a varied way; i.e., no milking was obtained in one of the three treatments, corresponding to 49% of the possible 55 partitions. No cows were milked by only one kind of cluster. The results supported the assumption that cows entered the milking parlor without external interference and by their own weak ordering mechanism, which also was consistent with the analysis of preferred areas in the milking parlor. Furthermore, results confirmed the importance of changing treatments rather than milking sites, even if cows enter the milking parlor in an unsorted way.

The modified Latin square design, despite the constraint of a minimum number of milkings per treatment, was at least as useful as the original method to minimize environmental disturbances and to evaluate the characteristics of milking machines applied to large herds.

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