ABSTRACT

The increased average Irish dairy herd size in a post-quota environment has put heightened pressure on grazing infrastructure. In a rotational grazing system, grazing infrastructure consists of the paddock system, which delineates the grazing areas into appropriately sized grazing parcels, and the roadway network, which connects these paddocks to the milking parlor. Where herd size has increased without corresponding adaptations to the infrastructure, farm management and roadway network performance has been affected. The links between suboptimal grazing infrastructure and roadway network efficiency are poorly understood and not widely documented. The aims of this study were to (1) analyze the effect of herd expansion and paddock size on pasture allocations per paddock, (2) identify the factors that affect the total distance walked per year, and (3) create a metric to compare the efficiency of roadway networks across farms of varying grazing platforms. A sample population of 135 Irish dairy farms with a median herd size of 150 cows was used for this analysis. Herds were split into the following 5 categories: <100 cows, 100 to 149 cows, 150 to 199 cows, 200 to 249 cows, and ≥250 cows. Herds with ≥250 cows had a greater number of paddocks per farm and rotated around the grazing paddocks more frequently, with 46% of paddocks only suitable for 12 h allocations relative to herd size, compared with just 10% to 27% of paddocks for herds with <100 cows to herds with 200–249 cows. When predicting the total distance walked per year on each study farm, the mean distance from a paddock to the milking parlor was the strongest indicator ($R^2 = 0.8247$). Other metrics, such as herd size, have failed to account for the location of the milking parlor relative to the grazing platform. The creation of the relative mean distance from a paddock to milking parlor (RMDMP) metric allowed the calculation of a farm’s roadway network efficiency for moving the herd between paddocks and the milking parlor. The analyzed farms increased their efficiency in terms of RMDMP (0.34–40.74%) as they increased herd size post quota. However, the position of new additional paddocks relative to the milking parlor substantially affected their RMDMP.

Key words: pasture allocation, walking distance, herd expansion, laneway network efficiency

INTRODUCTION

Irish dairy farming can retain a competitive advantage in the global market and improve system sustainability by continuing to prioritize a low-cost grass-based system of milk production (Cele et al., 2021). Currently, 95% to 100% of dairy farms in Ireland are defined as pasture-based compared with other European countries where this ranges from 15% to 95% (van den Pol-van Dasselaar et al., 2020). Ireland’s climate allows farmers to grow large quantities of grass over a long growing season (O’Donovan et al., 2011), whereas a compact spring-calving pattern enables pasture to provide a large proportion of the diet throughout lactation (O’Brien et al., 2018).

Following the removal of milk quotas in 2015 (Kelly et al., 2020), the average dairy herd size across Ireland has increased from 70 cows in 2014 to 90 cows in 2021 (Central Statistics Office, 2020; ICBF, 2021). It is widely accepted that the use of pasture is critical to improve farm profitability (Beukes et al., 2019; Garcia et al., 2020), with grazed grass the cheapest source of feed on pasture-based farms (Finneran et al., 2012). Each additional ton of herbage used is worth between €173 to €268/ha (Ramsbottom et al., 2015; Hanrahan et al., 2018). To maximize pasture utilization, a rotational grazing system is required, whereby the grazing herd is continually allocated fresh pasture as they move around the grazing area (delineated into grazing paddocks for ease of management; Roche et al., 2017). An integrated farm laneway network (referred to as a roadway network in Irish grazing systems) is required to connect the milking parlor to all areas of
the grazing platform, which can be defined as an area graze-able by the dairy herd in situ (Patton et al., 2016) to use grass efficiently (Hanrahan et al., 2019). This is particularly important in the spring and autumn period where suboptimal soil conditions can lead to excessive treading damage to the soil structure (Kennedy et al., 2011; O’Loughlin et al., 2016).

In a pasture-based system, it can be difficult to achieve high DMI across the herd while also ensuring high pasture utilization (McEvoy et al., 2009). Pasture allocation (PA) may be defined as the number of 12-h allocations achievable by a dairy herd from a paddock’s total available herbage (kg of DM), whereas PA frequency is how often fresh pastures are allocated over a given time period for grazing animals (Pollock et al., 2020). The allocation of fresh pasture can result in short-term differences in both grass availability and interanimal competition for feed (Pollock et al., 2020). Similarly, the frequency of allocation can affect rumination and milk production (Verdon et al., 2018). Animals offered fresh allocations of herbage frequently consumed similar quantities of herbage throughout the day (Dalley et al., 2001). However, frequent allocations resulted in poorer digestion, reducing energy utilization for milk production (Gregorini et al., 2017). Pulido et al. (2015) reported no difference in milk production through varying PA frequencies; however, this study failed to include any primiparous animals. Reducing grazing pressure through lax grazing strategies will increase milk yield (McEvoy et al., 2009); however, this will reduce sward quality over the grazing season (Tuñon et al., 2014), whereas increasing the length of time a paddock is grazed can negatively affect plant growth (Donaghy and Fulkerson, 1997). Pollock et al. (2020) reported the optimal allocation of fresh pasture to be every 36 h, which resulted in an increase in milk energy output compared with every 12- or 24-h allocations for primiparous animals. Taweel et al. (2004) previously reported that over 40% of the time spent grazing occurs at dusk, where pasture is not limited, whereas another major grazing event occurs at dawn (Gibb et al., 1996). Where fresh feed is offered frequently, there are increased feed bouts throughout the day, which increases competition for fresh feed (DeVries et al., 2003). A social dominance structure exists within each dairy herd, with dominance correlated with lactation and BW, placing primiparous animals as subordinates (Phillips and Rind, 2002; Hussein et al., 2016). The implementation of 36-h allocations reduces the frequency of fresh pasture, resulting in similar grazing patterns to the reported with set stocking management of 3 to 5 grazing events per day (Gregorini, 2012), indicating reduced competition for pasture when compared with 12- or 24-h treatments (Pollock et al., 2022). Following the removal of milk quotas in Ireland, it is hypothesized that as herd size increased, paddock size (ha) may have remained static, resulting in reduced herbage allowance per animal and increasing the frequency of fresh PA. This has been shown to negatively affect primiparous milk solid production (Pollock et al., 2020). The opportunity to reduce competition through lax grazing to ensure adequate intake is also limited as pasture utilization is a key metric for farm profitability on dairy farms (Hanrahan et al., 2018; Garcia et al., 2020).

The total distance walked per year (TDWY; km) by dairy cows on farm roadways over the grazing season is defined as the total distance walked from a paddock to the milking parlor and return trip to a paddock after milking over the grazing season. No previous research to date has analyzed the TDWY on commercial dairy farms. Most studies have measured the maximum distance from a paddock to the milking parlor (MAXDP; m) with Beggs et al. (2015) reporting that, in Australia, herds <150 cows had a MAXDP of 1,100 m. Similarly, Crossley et al. (2020) reported that Irish dairy herds with a mean herd size of 124 cows, had a MAXDP of 989 m. These results do not take into account the size of the grazing platform or milking parlor location within the grazing platform, which can vary greatly between farms and substantially affect the distance walked from a paddock to the milking parlor, regardless of the maximum distance to a paddock (Chesterton, 2011). Since the expansion of dairy farms post quota, it is unknown if farms have adapted their grazing infrastructure to meet increased herd demand. The aims of this study are to (1) analyze the effect of herd expansion and paddock size on grassland management techniques, (2) identify the factors that affect the TDWY on commercial farms, and (3) create a metric to compare the efficiency of roadway networks across a range of grazing platform sizes and the effect of the milking parlor location within the grazing platform has on the efficiency of the relative mean distance from a paddock to the milking parlor (RMDMP; m/ha) of any given farm.

MATERIALS AND METHODS

Farm Selection

No human or animal subjects were used, so this analysis did not require approval by an Institutional Animal care and Use Committee or Institutional Review Board. Before farms were recruited for this study, selection criteria were established to ensure the selected population of farms were representative of pasture-based dairy systems in Ireland. Herds were selected from a target range of 30 to 760 cows to gather
a large range of herd sizes, while also capturing farms that have recently expanded since the removal of milk quotas in 2015 (Kelly et al., 2020). All farmers were required to have an active account on Pasturebase Ireland (PBI), which is an online platform on which farmers input grassland management information for each paddock on the farm (Hanrahan et al., 2017). All farmers were required to have an active account on Pasturebase Ireland (PBI), which is an online platform on which farmers input grassland management information for each paddock on the farm (Hanrahan et al., 2017). Any herd selected was required to have a minimum of 25 grass cover measurements completed annually (Hanrahan et al., 2017). Herd size was based on June 2020 recordings on the PBI database, a period of the year where the maximum number of cows are in lactation to coincide with peak pasture growth. In total, there were 1,254 farms that matched the selection criteria. The distribution of herd sizes nationally was used to select representative sample sizes for each herd size category, which was previously delineated into 22 subcategories (Kelly et al., 2020). A minimum of 3 farms from each of these herd size categories was selected for the study to remove variability from an individual farm representing a herd size category. In total, 178 farmers were invited to participate, of which 138 accepted this invitation. However, 3 were later removed due to inaccurate data, resulting in 135 farms for the study. This was 10.8% of the sample population and was deemed an appropriate sample size for this study due the limitations of labor required to assess all individual farms in the study.

Farms were selected from a range of agro-climatic regions on differing soil types across Ireland. The farms were located in the following counties with the number of farms in parentheses: Carlow (4), Cavan (4), Clare (4), Cork (19), Donegal (4), Galway (6), Kerry (6), Kildare (4), Kilkenny (8), Laois (7), Limerick (11), Longford (2), Louth (1), Mayo (3), Meath (4), Monaghan (5), Offaly (6), Roscommon (4), Sligo (2), Tipperary (12), Waterford (7), Westmeath (4), Wexford (7), and Wicklow (4; Figure 1).

Data Collection and Analysis

Data were collected from February to April 2021. An up-to-date map of grazing platform and GPS coordinates of each farm were gathered, which detailed the identification number of each paddock, while also outlining the position of the milking parlor and all farm roadways. This was required to identify the path taken from each individual paddock to the milking parlor. Following the collection of data from the farmer, all pasture data were gathered from the PBI database. Information used in this study included the total number of paddocks (n = 3,661), paddock size, pre-grazing herbage mass (PGHM; kg DM/ha), days at grass over the grazing season, annual tonnage of herbage produced (tonnage of DM/ha), and the mean number of grazings achieved per paddock. The total herbage available in each paddock was divided by the demand of the herd to determine whether the paddock in question was suitable for a 12-, 24-, 36-, or 48-h allocation, or greater. In this study, PA per paddock of 12-, 24-, 36-, or 48-h allocations were defined as 1, 2, 3, or 4 allocations, respectively, as is practiced on commercial farms, whereby 1 allocation is defined as the period between successive milkings.

The PA was calculated as follows:

$$PA_i = \sum_{i=1}^{n} \frac{C_i H_i}{MD}$$  \[1\]

where $C_i$ is the PGHM of paddock $i$, $H_i$ is the area of the paddock (ha), $i$ is the number of paddocks on grazing platform, $M$ is the number of animals in the herd, and $D$ is the total daily herbage allowance (kg

Table 1. The sample size, mean, SE, and range are reported for each herd size category

<table>
<thead>
<tr>
<th>Category</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
<th>H4</th>
<th>H5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size (n)</td>
<td>25</td>
<td>42</td>
<td>20</td>
<td>14</td>
<td>34</td>
</tr>
<tr>
<td>Mean herd size</td>
<td>76 (±3.56)</td>
<td>124 (±2.27)</td>
<td>171 (±3.37)</td>
<td>220 (±3.41)</td>
<td>388 (±20.52)</td>
</tr>
<tr>
<td>Range in herd size</td>
<td>40-99</td>
<td>100-149</td>
<td>150-196</td>
<td>200-243</td>
<td>252-760</td>
</tr>
<tr>
<td>Mean grazing platform (ha)</td>
<td>25.78 (±0.56)</td>
<td>44.48 (±0.14)</td>
<td>56.72 (±0.10)</td>
<td>75.4 (±12.79)</td>
<td>120.96 (±41.26)</td>
</tr>
<tr>
<td>Range in grazing platform (ha)</td>
<td>12.4-45.2</td>
<td>24.0-64.2</td>
<td>43.6-81.6</td>
<td>43.6-94.1</td>
<td>70.4-254.9</td>
</tr>
</tbody>
</table>

*Means, within a row without a common superscript are significantly different (P < 0.05).

1H1 = <100 cows; H2 = 100 to 149 cows; H3 = 150 to 199 cows; H4 = 200 to 249 cows; H5 = ≥250 cows.
of DM per cow per day) of pasture for each animal in the herd. Pre-grazing herbage mass was assumed to be 1,400 kg of DM per hectare (Wims et al., 2014) when calculating PA to remove alterations individual farmers may have implemented to their PGHM to adapt undersized paddocks for a specific allocation, whereas total daily herbage allowance was assumed to be 17 kg of DM per livestock unit (Kennedy et al., 2003).

The distance from the entry point of each paddock to the milking parlor was measured for each study farm (3,661 paddocks in total) using satellite imagery (Google Maps, 2022).

Figure 1. The locations of farms (n = 135) selected for the study. Herd sizes are color coded as follows: blue: <100 cows, red: 100 to 149 cows, purple: 150 to 199 cows, green: 200 to 249, yellow: ≥250 cows. The underlying satellite image was mapped using Google (Google Maps, 2022).
The mean distance from a paddock to the milking parlor (MDP) was calculated as follows:

\[ MDP = \frac{1}{n} \sum_{i=1}^{n} X_i, \]  

where \( X_i \) is the distance (m) to milking parlor from paddock entry point \( i \), and the \( n \) is the number of grazing paddocks within the grazing platform.

The MAXDP was calculated as follows:

\[ \text{MAXDP} = \max(X_1, \ldots, X_n), \]  

where max is the maximum value for \( X_i \), \( X \) is the distance (m) from the entry point of a paddock within the grazing platform to the milking parlor and \( n \) is the number of grazing paddocks within the grazing platform.

To calculate the TDWY by the herd, the annual number of grazings per paddock was recorded. The average PGHM practiced on farm was combined with the paddock size to calculate the actual PA implemented on each farm based on the predicted DMI of the herd. This allowed for the number of trips to each paddock over the grazing season to be calculated, which was combined with the recorded distance (m) to each paddock entry point, allowing the TDWY to each paddock to be calculated.

The TDWY was calculated using the following equation:

\[ \text{TDWY} = \sum_{i=1}^{n} \left( X_i G_i PA_i \right), \]  

where \( X_i \) is the distance to the milking parlor from paddock \( i \) (m), \( G_i \) is the annual number of grazings in paddock \( i \), \( PA_i \) is the PA in paddock \( i \) (based on the actual PGHM recorded on PBI), and \( n \) is the number of grazing paddocks within the grazing platform.

The factors that influence the TDWY by the herd were analyzed. The coefficient of determination \( R^2 \) was employed as a correlation metric to determine the factors that affected the TDWY on each farm. Factors assessed included herd size, grazing platform size (ha), PA, MDP (m), and the MAXDP (m).

To assess the efficiency of a farm’s grazing infrastructure for the movement of animals, the RMDMP (mean distance to a paddock per grazing platform size, ha) and total distance walked each year per herd size (TDWYH; kilometers per herd size) were used. These methods were employed to normalize all farms relative to grazing platform size and herd size. Below is Equation 5, which calculates the RMDMP on a given farm:

\[ \text{RMDMP} = \frac{\sum_{i=1}^{n} X_i}{gp}, \]  

where \( X_i \) is the distance to the milking parlor from paddock \( i \) (m) and \( n \) is the number of grazing paddocks within the grazing platform and \( gp \) is the grazing platform area (ha). Equation 6 explains TDWYH as follows:

\[ \text{TDWYH} = \frac{\sum_{i=1}^{n} (X_i G_i PA_i)}{m}, \]  

where \( X_i \) is the distance to the milking parlor from paddock \( i \) (m), \( G_i \) is the annual number of grazings in paddock \( i \), \( PA_i \) is the PA in paddock \( i \) (based on the actual PGHM recorded on PBI), \( n \) is the number of grazing paddocks within the grazing platform, and \( m \) is the herd size of the farm.

**Assessing the Effect of Herd Expansion**

A subset of 113 dairy farms, which were active dairy farms in 2015 (pre-abolition of milk quotas), were used to assess the effect of herd expansion on grazing infrastructure. These farms were clustered into 5 groups using k-means clustering (Yan et al., 2013). Clustering analysis is a data reduction technique designed to group similar observations in the data set based on minimizing the Euclidean distance between points in each group, while maximizing the distance between groups (Na et al., 2010). The farms were clustered using 3 variables, which were herd size, MDP, and TDWY, with the recommended number of clusters required to be 5 based on the within sum of squares as a measure of the variability within each cluster. The MDP and TDWY were selected due to the strong correlation between these variables. Herd size was selected to compare the effect of herd expansion on the MDP. Two farms with the closest Euclidean distance to the centroids of each group were selected for further investigation of the MDP in 2015, resulting in 10 farms selected (Figure 2). These 10 farms were classified as a representative sample of all 113 dairy farms and were assessed for their RMDMP in 2015. The purpose of this analysis was to identify if farms had increased or decreased their respective RMDMP values since quota abolition.
Statistical Analysis

All data cleaning, descriptive statistics, and statistically significant differences were examined using R software version 4.0.2 (R Core Team).

All groups were first checked for normality for the various parameters assessed using a Shapiro-Wilk test. Following this, to determine the difference between the values obtained across the herd size ranges, a 1-way ANOVA was used with homogeneity of variance specified as true or false depending on the outcome of a Levenes test. Where results were deemed significant based an ANOVA test, a post hoc Tukey test was carried out where equal variance was reported. Where variance was unequal, a Games-Howell test was used. Results were deemed significant based an ANOVA test, a post hoc Tukey test was carried out where equal variance was reported. Where variance was unequal, a Games-Howell test was used.

RESULTS

Pasture Allocation

Farms in H1 had a PA of 2.7 per paddock, which was larger than herds in class H3, H4, and H5 ($P < 0.05$). Herds in H2 did not statistically differ from H1, H3, or H4. However, we found a significant difference when compared with herds >250 cows (H5; $P < 0.05$) (Table 2), where herds in H5 had the smallest PA per farm at 1.7 allocations per paddock (Table 2). Farms in H5 also had a higher proportion of the grazing platform (46%) suitable for 1 PA when compared with all other groups with the exception of H3 ($P < 0.05$; Table 2). As herd size increased, we detected a negative correlation with PA ($r = -0.5838$, $P < 0.05$). However, we found a positive correlation between herd size and the number of paddocks within the grazing platform ($R^2 = 0.3125$, $P < 0.01$; Figure 3). It is important to note herd size had no effect on PGHM (kg of DM/ha) over the grazing season ($R^2 = 0.044$), which reduced the potential

![Cluster plot](image)
variability in practiced PA between farms. Therefore, herd size was the primary influential factor affecting PA.

**Herd Size Affecting Walking Distance on Farm**

The MDP was assessed across the study farms, with herds in H5 having a significantly greater MDP than all other groups (633.5 m, \( P < 0.05 \)). As herd size increased, we found an increase in the MDP, with the exception of herds in H4 (Table 3). We detected a positive correlation present between herd size and MDP \( (R^2 = 0.4119, P < 0.01) \).

Herd size had a similar effect on the TDWY with a positive correlation \( (R^2 = 0.4535, P < 0.01; \) Figure 4), where TDWY increased relative to herd size. Herds in H1 walked 385.5 km/yr. This increased to 718.2 km/yr for herds in H5, significantly further than any other herd size category \( (P < 0.05) \).

Smaller herds \(<100\) cows, H1) had a shorter MAXDP within the grazing platform relative to all other groups, with the exception of herds in H4 \( (P < 0.05; \) Table 3). The correlation between MAXDP and herd size was significant \( (R^2 = 0.3806, P < 0.01) \), resulting in larger herd sizes \( (H5) \) having the greatest MAXDP within the grazing platform \( (1,452.53\) m).

**Factors Affecting Total Walking Distance per Year**

The TDWY correlated positively with herd size \( (R^2 = 0.4535, P < 0.01) \). Grazing platform size \( (ha) \) positively correlated with TDWY \( (R^2 = 0.4891, P < 0.01) \). The MDP had the strongest positive correlation with TDWY of all variables assessed \( (R^2 = 0.8247, P < 0.01; \) Figure 5), whereby an increase in the MDP had a large effect on the TDWY. The MAXDP had a weaker correlation than MDP with an \( R^2 = 0.6395 \) \( (P < 0.01) \), but this was still a stronger indicator of the TDWY when compared with the herd size or the grazing platform size \( (ha) \).

**Efficiency Metrics of Farm Roadway Networks**

An assessment of the correlation between the RMDP and TDWYH revealed an \( R^2 = 0.6689 \) \( (P < 0.01; \) Figure 6). As herd size increased, the RMDMP and TDWYH both reduced, whereas smaller farms tended to have an increased RMDMP and TDWYH. Larger herds were significantly more efficient in relation to RMDMP and TDWYH when compared with other herd size categories in the study, with H4 and H5 differing from smaller herd sizes for RMDMP \( (Table 4) \).

Two farms were selected to provide a visual description of the effect the location of the milking parlor with respect of the grazing platform has on RMDMP. Farm A (herd size: 415 cows, grazing platform: 114.7 ha; Fig-
Figure 4. Effect herd size (cows) has on total distance walked per year (km). Red line is the trendline.

Figure 5. Effect mean distance from a paddock to the milking parlor (m) has on the total distance walked per year (km). Red line is the trendline.

ure 7) was selected from H5 (≥250 cows), whereas farm B (herd size: 67 cows, grazing platform: 21.7 ha; Figure 7) was selected from H1 (<100 cows). The RMDMP for farm A was 3.8 m/ha, whereas this increased to 19.1 m/ha for farm B. The TDWYH followed a similar trend with a TDWYH for farm A of 1.2 km/cow and the TDWYH increasing for farm B to 8.0 km/cow, despite having a smaller herd size.

Assessing the Effect of Herd Expansion

Of the 10 representative farms selected for this assessment (based on the clustering analysis), the mean herd size was 209 ± 35.8 in 2020, whereas it was 142 ± 26.4 (P < 0.05) in 2015. We found no significant difference in the MDP, increasing from 442.2 ± 44.3 m in 2015 to 543.8 ± 58.4 m in 2020 (P = 0.183). However, the location of additional paddocks accessed (between 2015 and 2020) in relation to the milking parlor did explain whether farms expanded efficiently or inefficiently, resulting in an increased or decreased RMDMP, respectively. Although no farm reduced their RMDMP through expansion in the current study, 50% farms saw a reduction in their RMDMP of less than 10%, whereas their grazing platforms increased by 8% to 26%. Some farms greatly reduced their RMDMP from 2015 to 2020, such as farm C (Figure 8) where the RMDMP reduced by 40.7% from 11.3 m/ha to 6.7 m/ha when herd size of the farm increased by 91.0% and the grazing platform grew by almost 91.7%. The MDP of farm C also increased by 60.2 m between 2015 and 2020. However, the RMDMP remained almost static

Table 3. The association of herd size with mean distance to a paddock (m), total distance walked per year (km), and maximum distance to a paddock (m)

<table>
<thead>
<tr>
<th>Category</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
<th>H4</th>
<th>H5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size (n)</td>
<td>25</td>
<td>42</td>
<td>20</td>
<td>14</td>
<td>34</td>
</tr>
<tr>
<td>Mean distance to a paddock (m)</td>
<td>340.25c (±23.01)</td>
<td>472.87bc (±22.29)</td>
<td>500.55b (±32.94)</td>
<td>473.32bc (±33.44)</td>
<td>633.54a (±31.58)</td>
</tr>
<tr>
<td>Range mean distance to a paddock (m)</td>
<td>166.16–569.83</td>
<td>246.09–905.88</td>
<td>320.04–932.81</td>
<td>276.65–681.55</td>
<td>312.57–1,020.42</td>
</tr>
<tr>
<td>Mean total distance walked per year (km)</td>
<td>385.50c (±25.75)</td>
<td>480.75bc (±26.66)</td>
<td>542.83b (±33.79)</td>
<td>572.00b (±35.31)</td>
<td>718.22a (±35.53)</td>
</tr>
<tr>
<td>Range total distance walked per year (km)</td>
<td>196.95–662.58</td>
<td>246.19–920.50</td>
<td>343.10–918.88</td>
<td>354.07–801.98</td>
<td>435.20–1,141.57</td>
</tr>
<tr>
<td>Mean maximum distance to the milking parlor from a paddock (m)</td>
<td>712.32c (±42.65)</td>
<td>995.50b (±60.45)</td>
<td>1,193.35abc (±85.79)</td>
<td>1,046.00bc (±72.13)</td>
<td>1,452.53a (±74.11)</td>
</tr>
<tr>
<td>Range maximum distance to the milking parlor from a paddock (m)</td>
<td>361–1,099</td>
<td>555–2,602</td>
<td>673–2,123</td>
<td>588–1,480</td>
<td>689–2,640</td>
</tr>
</tbody>
</table>

a–cMeans within a row without a common superscript are significantly different (P < 0.05).

1H1 = <100 cows; H2 = 100 to 149 cows; H3 = 150 to 199 cows; H4 = 200 to 249 cows; H5 ≥250 cows.
for farm D (Figure 8), decreasing by 0.3%, from 14.8 m/ha to 14.4 m/ha, when the herd size increased by 24.8% and the grazing platform expanded by 25.1%. The MDP of farm D increased by 139.4 m between 2015 and 2020.

**DISCUSSION**

From the 135 farms assessed in this study, it was discovered that as herd size increases on farm, there is a reduction in the PA of each paddock, with 46% of paddocks only suitable for 1 PA on farms with 250 cows or greater. The MDP was identified as the most influential factor to affect TDWY on commercial farms. To the authors’ knowledge, this is the first study to create a metric (RMDMP) to benchmark farms of ranging grazing platform sizes on their roadway network efficiency for animal movement and the effect the location of the milking parlor within the grazing platform has on the roadway network efficiency.

**Pasture Allocation**

It was discovered that farms with larger herd sizes within our sample population had a reduced PA per paddock compared with farms with smaller herd sizes, whereas the number of paddocks per farm increased with herd size ($R^2 = 0.3125$). This finding indicates that farms with larger herd sizes tended to have more paddocks per farm ($n = 33.09 \pm 1.52$). However, many of these paddocks are inadequate in size relative to herd size and, as a result, can only facilitate low PA ($n = 1.69 \pm 0.08$). Pollock et al. (2020) has previously reported that reducing PA to every 12 h has a significant negative effect on milk solid production for primiparous animals within the herd. This may affect the milk solid production of primiparous animals in larger herd sizes in current study, where a greater proportion of 12-h allocations is implemented. Fallon et al. (2021) reported that the number of paddocks per farm should range between 14 and 23, enabling paddocks to be suitable for 36- or 24-h allocations where a 21- to 23-d grazing rotation is implemented. Results from this study suggest that herds in the H1 category are achieving this target, with all other herd size categories having a greater number of paddocks per farm than recommended.

**Herd Size Effecting Walking Distance on Farm**

Previous research has only investigated the MAXDP on commercial farms (Beggs et al., 2015, 2018; Crossley et al., 2020), but this was limited to a questionnaire.
with farmers as opposed to this study where it was measured directly using satellite imagery. The mean MAXDP across the current study is 1,092.7 ± 440 m, which was similar to that discovered by Beggs et al. (2015) and Crossley et al. (2020) who reported a MAXDP of 1,100 and 989 m, respectively. In the current study, we detected a moderate correlation between herd size and MAXDP ($R^2 = 0.3806$), with farms with larger herd sizes having a greater MAXDP. We found one exception to this trend, which was the herds in H4. This may be due to the greater efficiency of movement of animals from a paddock to the milking parlor on farms in this herd size category, as the RMDMP of these farms was significantly lower than that of H1, H2, or H3.

Beggs et al. (2018) had previously reported that the number of steps taken per day was influenced by where the cows were located within the grazing platform. A similar result was evident in the current study when assessing the TDWY, whereby the MDP proved to be the strongest indicator of the TDWY across the study farms, with farms in the H5 category having almost twice the MDP at 633.5 ± 184.1 m when compared with those in the H1 category at 340.3 ± 23.0 m. It has previously been reported that an increased walking distance to pasture can affect milk production (Thomson and Barnes, 1993; D’hour et al., 1994; Coulon et al., 1998) and can lead to reduced time at pasture (Neave et al., 2021). This increased TDWY experienced by herds in H5 may affect the milk production of these animals. There may also be a higher labor requirement to move animals to and from the milking parlor with herds in the H5 category, due to a greater MDP. This is a similar result to that described by O’Donovan et al. (2008) and Deming et al. (2018) where an increase in the total hours per year for milking activities as herd size increases.

**Factors Affecting Total Distance Walked per Year**

In the current study, it was found that there were 4 major factors that are positively correlated with TDWY. Herd size and grazing platform (ha) had similar positive correlations with TDWY ($R^2 = 0.4535$ and $R^2 = 0.4891$, respectively). This was expected as the stocking rate across all farms remained similar to that in previous studies for intensive pasture-based farms (Macdonald et al., 2008; McCarthy et al., 2013). The

![Farm A](image1)
![Farm B](image2)

**Figure 7.** Farm maps displaying the farmyard location within the grazing platform. Red box: farmyard location within the grazing platform.
MAXDP also had a strong positive correlation with the TDWY ($R^2 = 0.6395$). Therefore, knowing the MAXDP can provide a greater insight into the TDWY of a farm than that provided by herd size or the grazing platform size. However, the MAXDP can be an unreliable metric, particularly in relation to location of the furthest paddock with respect to the milking parlor location within the grazing platform. There were farms in the current study where the furthest paddock did not directly adjoin the other paddocks within the grazing platform and was accessed via a public (or private) roadway, similar to farm D. This has a major effect on the MAXDP, as the furthest paddock from the milking parlor may be described as an outlier when compared with all other paddocks within the grazing platform, when accessed via a public (or private) roadway. There are cases where the MAXDP can provide a similar insight to the TDWY as that provided by the MDP, where the milking parlor is centrally located and no paddocks are located away from all other paddocks within the grazing platform, as is the case with farm A. However, it was discovered that the MDP had the strongest positive correlation with TDWY of any of the factors assessed ($R^2 = 0.8247$). This is due to the MDP accounting for variation of the milking parlor location within the grazing platform, but also the limitations of MAXDP caused by the location of the furthest paddock with respect of all other paddocks within the grazing platform. If researchers wish to quantify the TDWY on commercial farms for research, the MDP provides a better indication into the TDWY than the MAXDP.

**Factors Affecting Roadway Network Efficiency**

This study also investigated the effect of RMDMP as a metric to benchmark farms of various grazing platform sizes for the efficiency of their roadway networks for moving animals between a paddock and the milking parlor. It was demonstrated that larger farms were more efficient when assessed for the RMDMP. The main factor which affected RMDMP was the location of the milking parlor within the grazing platform. The milking parlor is centrally located on farm A (Figure 7) with a herd size of 415 cows, whereas it was located on the periphery of the grazing platform on farm B (Figure 7) with a herd size of 67 cows. We found no signifi-

![Figure 8. Farm maps displaying the farmyard location and new paddocks accessed within the grazing platform. Red box: farmyard location within the grazing platform. Yellow box: new paddocks added to grazing platform.](image-url)
cant difference in the MDP between farm A and farm B, despite the large difference in herd size. However, when assessed using RMDMP, farm A had a greater efficiency in the movement of animals from a paddock to the milking parlor, 3.8 m/ha for farm A compared with 19.1 m/ha for farm B. Larger farms were more efficient for RMDMP than smaller farms across the study farms. Using RMDMP provides a more accurate reflection of the farms’ roadway network efficiency. This metric may be useful for farmers who wish to upgrade their milking parlor facilities and farms which are new entrants to dairying from the other agricultural sectors. With 230 new entrants entering the dairy sector from 2009 to 2011 (McDonald et al., 2013), it may hypothesized that a similar number has entered the dairy sector in subsequent periods and following milk quota abolition. Although existing dairy herds have rapidly expanded their dairy enterprises since the abolition of milk quotas, whereby new milking facilities are being erected. It may be recommended that farms evaluate their RMDMP before selecting the position of the new milking parlor within the grazing platform.

The lower MDP and MAXMD reported for herds in H4 than those in H3 is due to more efficient roadway networks present on these farms and a more central location of the milking parlor within the grazing platform, with a mean RMDMP of 6.3 m/ha for herds in H4 compared with 9.0 m/ha for herds in H3. O’Donovan et al. (2008) has previously reported that farms have become more efficient in relation to hours worked per cow on the farm as herd size increases. A similar trend was observed in this study where farms became more efficient with respect to the RMDMP as grazing platform size increased, due to more centralized milking parlor locations within the grazing platform.

Grazing Platform Expansion Affecting Roadway Network Efficiency

When assessing the effect of grazing platform expansion on the RMDMP, the position of additional paddocks in relation to the milking parlor location on the RMDMP of a farm was evident. Farm C and farm D both added additional paddocks to the grazing platform. However, the location of these paddocks with respect of the milking parlor position was crucial in the effect they have on the farms respective RMDMP. Farm C added new paddocks to the grazing platform in close proximity to the milking parlor (Figure 8) with the RMDMP reducing by 40.7% and the MDP increasing by 60 m. On farm D, new paddocks were added on the outer most periphery of the grazing platform, resulting in only a 0.34% reduction in RMDMP and the MDP increasing by 139 m, which indicates the addition of new paddocks on the grazing platform may not always increase farm roadway network efficiencies. The milking parlor location within the grazing platform explains why there was a stronger correlation between MDP and TDWY than the correlation reported between herd size and TDWY. This is due to herd size failing to account for the milking parlor location within the grazing platform.

Results from this study suggest that for farms to improve their roadway network efficiency with respect to RMDMP, new paddocks should be assessed for their location with respect to the milking parlor before they are added to the grazing platform. However, this is not always possible on commercial farms; nonetheless, farmers may use the RMDMP to benchmark the efficiency of their roadway networks to herds of similar size. This may allow farms who have added new paddocks to the grazing platform creating inefficient roadway networks, adapt their management practices to first reduce walking distance per day on farms. Chesterton (2011) previously reported that reducing milking to once per day halved the distance walked per day, while breed selection on farms to reduce probability of lameness on farms (Lethbridge et al., 2008; Barker et al., 2010; Ranjbar et al., 2016). As it is widely reported in literature that the increased walking distance to a paddock can result in an increase in lameness on commercial farms (Chesterton et al., 1989; Lawrence et al., 2011; Doherty et al., 2014), it is recommended that current farm roadway network quality is evaluated to review the effect it may have on the efficient movement of the dairy herd between the milking parlor and grazing paddocks.

CONCLUSIONS

The study established that PA on commercial dairy farms has not adjusted to the increase in herd sizes in a post-quota era, with larger herds (H5) spending a larger proportion of the grazing season in 12-h allocations compared with all other groups. Herd size had a positive correlation with the TDWY. However, MDP had the strongest correlation predicting TDWY (R² = 0.8247) greater than that of the MAXDP, a metric used in previous studies. The RMDMP allowed farms of ranging herd sizes to be benchmarked for the efficiency of the roadway network. It was discovered that expansion did not have any negative effect on the RMDMP of the study farms. However, the position of new paddocks in relation to the milking parlor location had a substantial effect. It may be recommended that farms are assessed using RMDMP to calculate their roadway network efficiency as opposed to MAXDP, as is currently practiced.
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