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SUPER-G

SUSTAINABLE PERMANENT GRASSLAND

Deliverable 3.8

Modelling selected ecosystem service indicators from farm and permanent grassland management data

Project funded under the Horizon 2020 Research and Innovation Programme

Dissemination Level

PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Contact Details

Name of Contact: Sjaak Conijn

Address: Wageningen Plant Research, Wageningen, Netherlands

Telephone: +31 317 480544

Email: sjaak.conijn@wur.nl

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Summary

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Glossary of abbreviations

ESS	Ecosystem service(s)
DM	Dry matter
GHG	Greenhouse gas
LU	Livestock unit (see Annex 1)
PG	Permanent grassland
N	Nitrogen
t	Tonne (= 1000 kg)
UAA	Utilised Agricultural Area
UK	United Kingdom

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Abstract

In this study, farm data from the 2019 survey of 352 farms within task 3.1 of the SUPER-*G* project were used to investigate correlations between various farm characteristics and permanent grassland (PG) management variables of specialised dairy farms in Europe. These correlations were assessed through linear regression and their equations were combined in a synthesis model with the rent charge of PG and the farm size in Utilised Agricultural Area (UAA) as external inputs. The model illustrates how variables are connected and how they determine a number of farm characteristics and PG management options, and was used to calculate indicators of ecosystem service (ESS) delivery. The model demonstrates the dependency of milk production intensity (per ha) on the 'typical rent charge of PG in the area' via correlations with milk income, stocking rate of milking cows and milk production per cow. The model correlations also highlight how milk production was dependent on a combination of imported (purchased) feed and on-farm grass production from PG. These two feed sources are partly exchangeable, but purchased feed was clearly more important relative to on-farm PG grass production with higher milk production levels per ha. While forage efficiency (kg milk per kg feed) showed a positive relation with milk production intensity, this was not the case for fertiliser efficiency (kg grass dm from PG per kg manufactured N applied – at the farm level) for most of the specialised dairy farms. On average, more grass (i.e. dry matter production) from PG on the farm correlated with more manufactured N fertiliser use, which had a negative effect on PG plant species diversity. Possible reasons for the correlations and remaining uncertainties are discussed and topics for further research are identified. The correlations are based on spatial differences between selected farms within the SUPER-*G* farm networks, but the model may also be useful to gain more insight into the interlinkages between external drivers, farm structure, PG management, and some ESS for other dairy farms in Europe, because of the underlying 'logic' of the correlations.

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1. Introduction

Permanent grasslands (PG) in Europe are under pressure and in some regions their existence is threatened alongside the ecosystem services (ESS) they provide (see the SUPER-*G* project Description of Action for more background information). For example, they can be ploughed and used for (more profitable) arable crops or abandoned after which non-grassland species take over. This negatively affects the specific ESS that PG provides. Examples of these ESS are animal food provision, biodiversity, water regulation, cultural values and open landscapes. To halt the loss of PG and the ESS they provide, more needs to be known about their management and how this relates to the threats to their existence and the ESS they deliver. Because most PG in Europe are managed by livestock farmers, understanding their farm characteristics, PG management and motivation to use PG is crucial. For this reason, the SUPER-*G* project has undertaken a diverse range of research activities to identify and propose promising options to preserve PG and its ESS in Europe.

On a livestock farm, various activities are interlinked, such as animal productivity (often the main income source), feed provision for the animals (often partly purchased from outside the farm) and on-farm feed production (partly but not exclusively from PG). These interlinkages make livestock farms complex to study and understand the relations between various farm activities and to develop economically viable farm and PG management options.

In 2019, the SUPER-*G* project surveyed 352 farms across 12 countries. The survey provided valuable insights into the farming practices carried out within the SUPER-*G* farm networks with respect to PG management and related ESS (Mulvenna et al, 2021). In deliverable report 3.2, survey data were analysed by averaging farm characteristic and PG management data within the farm networks representing each biogeographical region in Europe, thereby highlighting the differences between the sets of farm networks. Additionally, this dataset has been used to analyse correlations between farm characteristics and PG management, irrespective of their location in Europe in an attempt to gain a complementary understanding. Moreover, the relations between ESS delivery and PG management can be studied to illustrate how ESS are connected, either by synergistic or by trade-off relations. A thorough understanding of these relations is needed to identify options for both an adequate supply of food under a growing demand in the future and simultaneously maintaining/improving environmental integrity which forms the basis of our food production system.

For this report (**Deliverable 3.8**: '*Modelling selected ecosystem service indicators from farm and permanent grassland management data*'), the survey data were re-examined, and a number of correlations was investigated that could be used for developing perspectives on viable PG management and balanced ESS delivery. This study is limited to correlations of specialised dairy farms because similar farm types share common challenges and due to project time and resource constraints. In order to explain the diversity of dairy farms in Europe, the correlations also need to be linked to external drivers that determine the socio-economic and/or environmental conditions under which farm businesses operate. Finally, a quantitative model based on 'actual' farm data, could be developed to apply the knowledge derived from the survey, in a structured way to a larger sample of dairy farms in Europe. This could illustrate wider perspectives beyond the farms of the survey.

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2. Objectives

This study has the following three objectives:

a. To gain a better understanding of the differences between European dairy farms with respect to their farm characteristics, PG management and related ESS.

b. To develop a quantitative model that links external drivers, such as prevailing land rent, to various farm characteristics and PG management.

c. To offer insights into how ESS are related on a dairy farm and illustrate possible synergies and trade-offs in the delivery of various ESS from current dairy farm practices in Europe.

The knowledge linked to the above three objectives may be helpful to improve PG management and to stimulate a broader delivery of ESS from PG in Europe.

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3. Methods

3.1 Farm selection

The 2019 task 3.1 SUPER-*G* farm survey contains information from 352 farms across six biogeographical regions in Europe and has been extensively described by Mulvenna et al. (2021). Their analysis was primarily based on comparing the farm data and investigating statistical differences between farms within farm networks from different biogeographical regions. For this report, the same database has been used, but a different approach was taken in analysing the data. Firstly, the farms have been categorized not by their location, but by their specialisation with respect to their main livestock species. The farm typology rules (Lombardi & Ravetto Enri, 2021) were used to distinguish and select specialised farms. Secondly, the farm data from specialised farms were analysed not by calculating averages per region, but by investigating correlations between various characteristics over the whole range of values from all regions.

The first level for selection was '*Livestock species and categories*' (Lombardi & Ravetto Enri, 2021) where a criterion was used to categorise farms by their main livestock species with the total livestock units (LU) of the main species being more than 75% of the total LU of all livestock species on a farm. The second level for selection was '*Stocking rate on total UAA*', although at this level all farms, irrespective of their stocking rate, were selected for analysis. The third and final level of selection related to '*PG share on total UAA*', with only those farms on which the PG area of the farm was more than 50% of the total farmed area being selected for analysis. Using these levels and criteria, 90 farms specialised in dairy farming were selected, combining all available intensity (stocking rate) levels and using most of their land for grass-based feed production. Dairy farms were selected as their abundance was highest among all livestock farms in Europe (26%; see Table 3, page 27 in Lombardi & Ravetto Enri, 2021); and >50% PG was used to reduce the number of farms with a relatively high production of arable crops that are not used to feed the dairy herd. These farms are described as '*specialised dairy farms*' and their

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data from the 2019 survey forms the basis of the analysis in this report. These specialised dairy farms were located in the following countries: Czechia (2), France (19), Italy (5), Montenegro (2), the Netherlands (17), Slovenia (26) and the UK (19), covering four different biogeographical regions. The motivation to use the above criteria was to select farms that on the one hand are similar in their farm business (milk is their main product and grass is their main feed type from the farm), while on the other hand they are (very) different with respect to their intensity of production per ha. Located in four different biogeographical regions also means that their social, economic and environmental conditions are diverse.

3.2 Description of the specialised dairy farms

Total farmed area (expressed in UAA) of the specialised dairy farms was mostly below 350 ha in 2019, while their PG area was mostly below 300 ha. The dataset of selected dairy farms has two distinct outliers with respect to PG area and total farmed area, viz. a farm in Czechia with 1,000 ha UAA and 650 ha PG and a farm in the UK with 650 ha UAA and almost 600 ha PG (Fig. 1).

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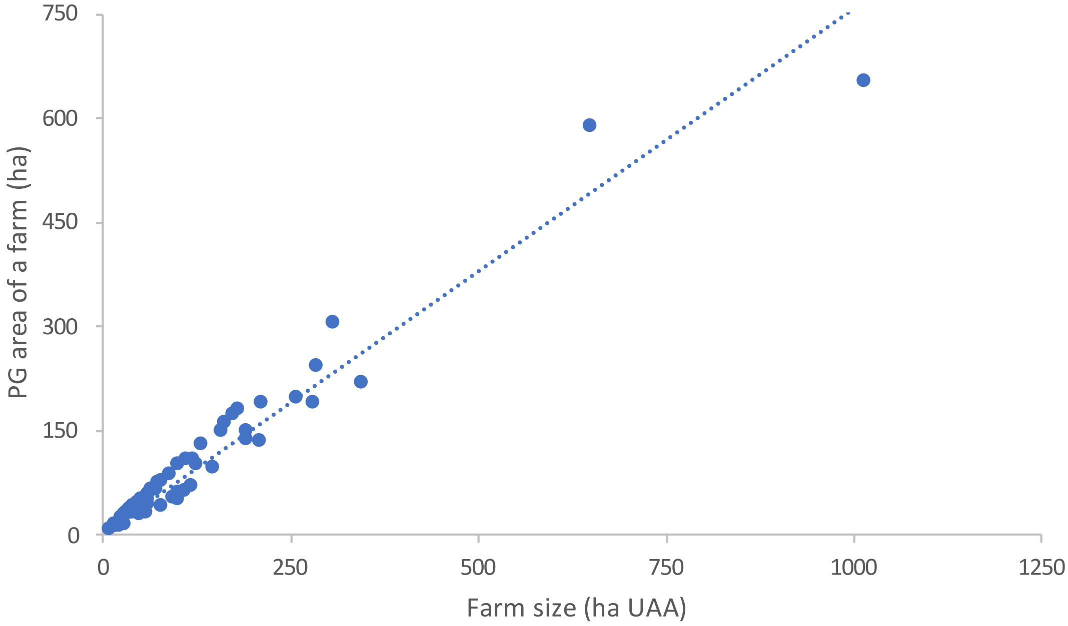

Figure 1. PG area per farm plotted against total farmed area of the specialised dairy farms from the 2019 survey. The dotted line results from a linear regression of PG area against total farmed area (y = 0.726 * x + 9.68).

The regression line in Fig. 1 does not illustrate a clear trend in PG area share (PG area divided by total farmed area) as a function of total farmed area. This is also visible in Fig. 2, where low and high PG area shares can be found over a wide range of total farmed area values. Due to the selection criteria (see section 3.1), the PG area share ranges from 0.5 to 1 with an average value of 0.84 (n=90) for the data in Fig. 2.

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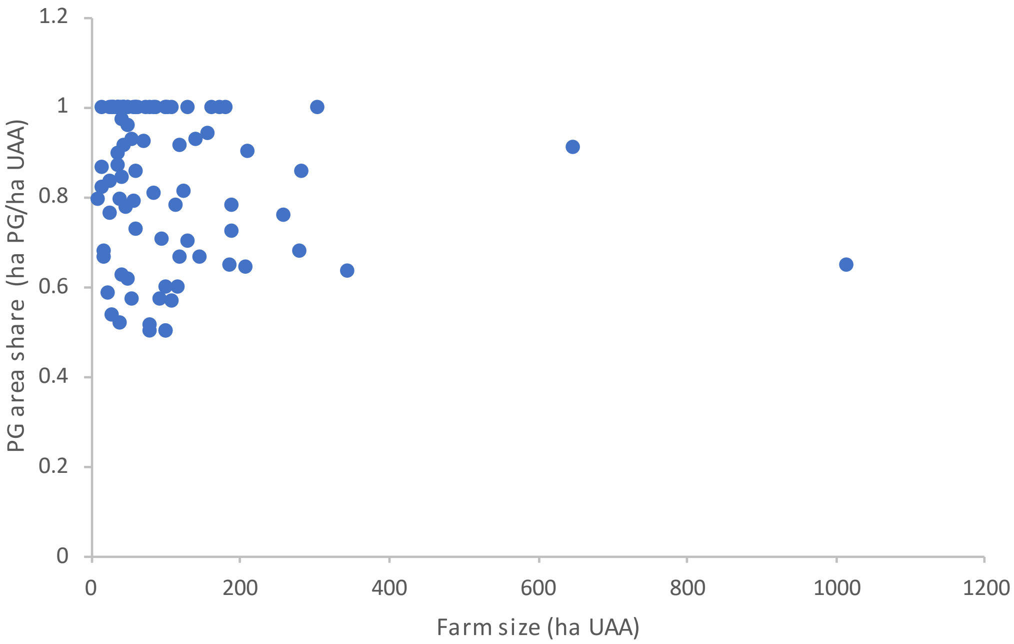

Figure 2. PG area share per farm plotted against total farmed area of the specialised dairy farms from the 2019 survey.

In the selected dataset, no clear relation was found between stocking rate (number of milking cows per ha of total farmed area) and total farmed area (Fig. 3). Most farms had stocking rate values of below 3 cows/ha. Fig. 3 shows three distinct outliers: two of them have been described above in combination with Fig. 1 and the third is a Dutch farm with a stocking rate of more than 5 cows/ha on a total farmed area of 38 ha. The average stocking rate of the selected 90 farms in Fig. 3 was 1.25 milking cow per ha UAA.

In most specialised dairy farms, the number of ruminants is higher than the number of milking cows, due to the presence of youngstock and breeding bulls, but also because other (non-dairy) ruminants can be part of the farm. The average fraction of additional ruminants relative to the number of milking cows equals 0.437 (n=83) without a clear trend with the number of milking cows in the data set (Fig. 4). In Fig. 4 and for the average fraction, seven farms from France were excluded that reported no additional ruminants next to their milking cows (fraction = 1). It is assumed that data on their youngstock was missing from the survey.

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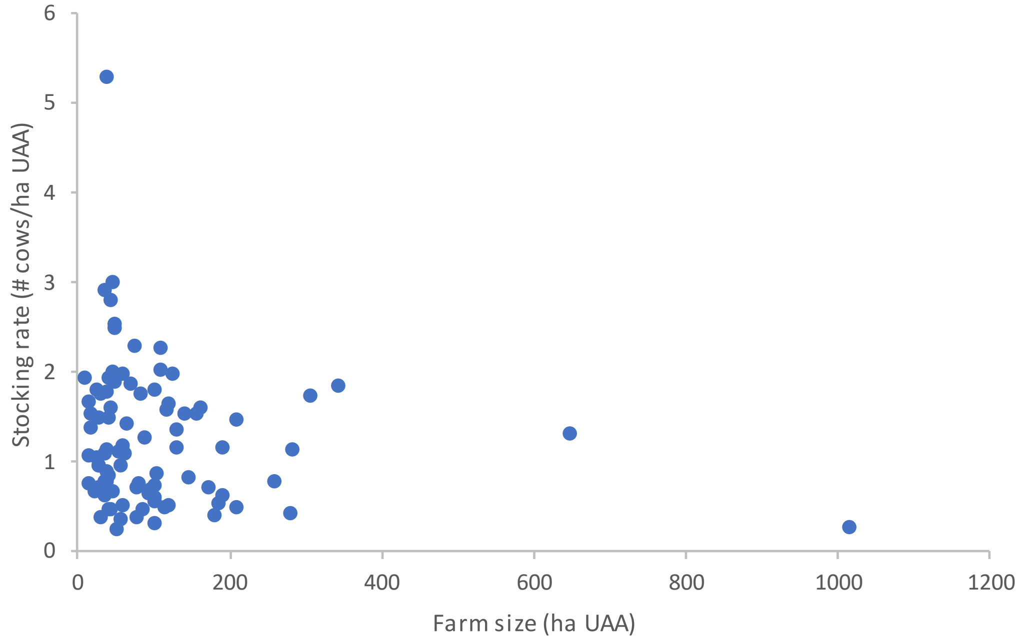

Figure 3. Stocking rate of milking cows per farm plotted against total farmed area of the specialised dairy farms from the 2019 survey.

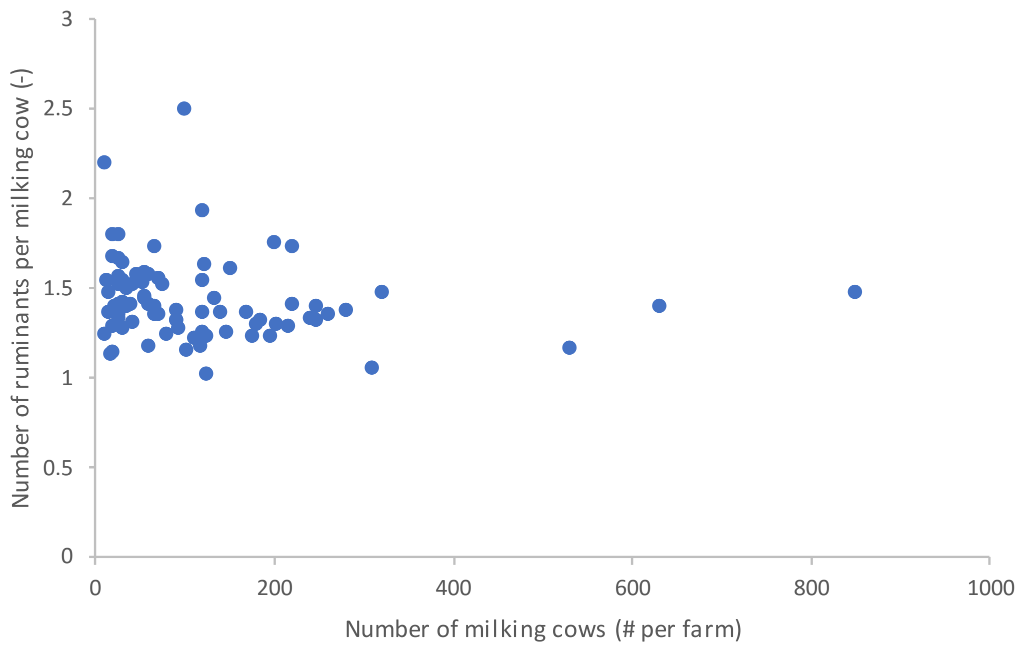

Figure 4. Total number of ruminants (dairy, beef, sheep and goat, expressed in LU) per milking cow plotted against number of milking cows of the specialised dairy farms from the 2019 survey.

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3.3 Correlation research

In chapter 4, correlations between variables were analysed by means of linear regression, performed in excel ('*Data analysis/Regression*'). In all situations different equations were tested in the linear regression, where for some situations, linear relations were found to be the best fit (e.g., in the form of y = a + b * x), while for other situations curvilinear relations gave better results (e.g., in the form of $y = a * x^b$). The choice for the 'best' regression equation mostly depended on the R^2 (see for explanation below), but in some cases also on the form of the curve, notably when a decreasing slope can be expected at e.g. higher x values.

For each correlation the R^2 or coefficient of determination of the regression equation is given, which equals the explained sum of squares (due to the regression) divided by the total sum of squares. The total sum of squares is calculated by the sum of squares of the difference between an observed y-value with the average observed y-value. The explained sum of squares equals the sum of squares of the difference between a calculated y-value (with the regression equation) and the average observed y-value (which is identical to the average calculated y-value). R^2 expresses the explained part of the variation in the observed values, while 1- R^2 represents the unexplained part.

While the total number of specialised dairy farms from the 2019 survey was 90 (see above), the number of data points in the correlations is often lower than 90, due to missing data in the survey (either in the x or the y values or in both). Depending on the combination of x and y values, the number of data points varies between 40 and 70. In two cases where y values were averaged to obtain unique values, the number of data points for the linear regression equals 10 and 13.

4. Results

In this chapter a number of correlations between various farm and PG characteristics of the specialized dairy farms of the 2019 survey are described. The focus is on illustrating the linkages between the characteristics in the context of various ESS, especially related to the indicators defined by Newell Price (2020). Finally, in section 5 (‘*Synthesis modelling*’) correlations are combined and used in a comprehensive model to estimate the delivery of a number of ESS as a function of either a financial/economic or an intensity variable, both referring to farm conditions.

4.1 Farm income from the main product

The first correlation links two economic variables, viz. income from milk production and PG rent charge (Fig. 5). Milk income was calculated by multiplying the milk production with an average milk selling price per country (see Annex 2) and is expressed per ha of total farmed area (UAA) per farm. The rent charge is the maximum value given in the survey for improved and unimproved PG, where in most cases only one value was given (either for improved or unimproved PG). The value for rent charge in the survey is supplied via the question of ‘*What is the typical rent charge per hectare (ha) in your area for PG (un)improved*?’ and does not necessarily represent the actual situation for the farmer, nor does it take into account how much PG land is actually rented relative to the total PG or farmed area of the farm. In this analysis rent charge is used as a proxy for the production costs by assuming that other costs besides PG rent charge are positively related to the PG rent charge. These costs need to be compensated for by the revenues of the farm by selling milk (products), being the main enterprise of specialised dairy farms.

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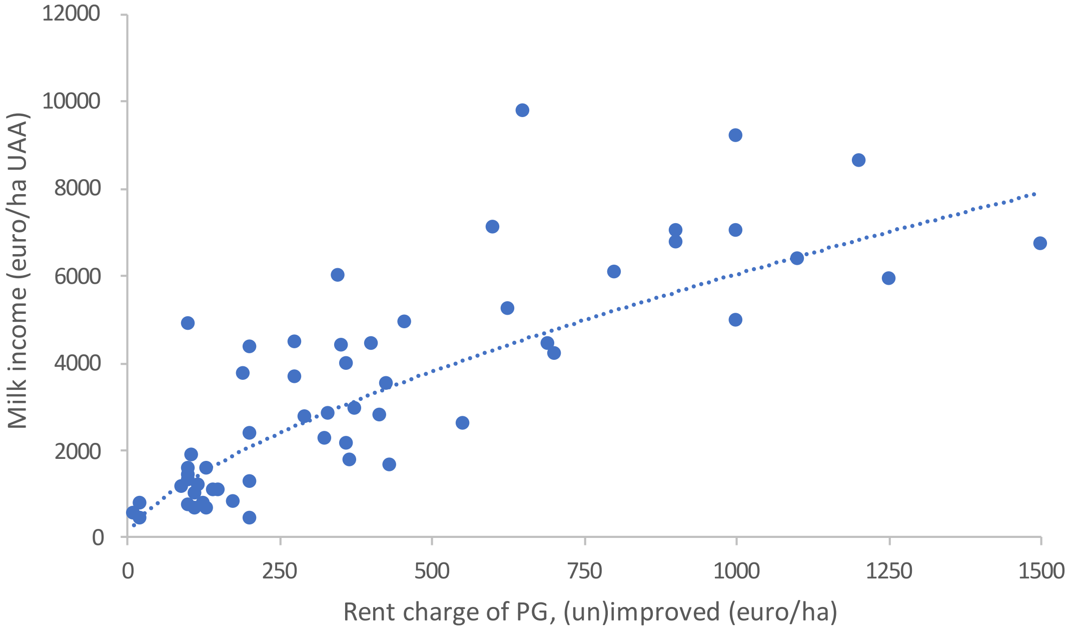

Figure 5. Correlation between annual milk income (y) and typical rent charge (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.68; n=56):

$$y = 61.3 * (x)^{0.665} \quad (1)$$

Next to the rent charge of PG (Fig. 5), the variation in milk income could not be further explained by additional variables, such as PG area as a fraction of UAA, kg (dairy) meat sold next to milk, number of dairy animals relative to total number of animals (both expressed in LU) or fraction of PG that is rented. Furthermore, any farm diversification as part of the farm business was not statistically significant when added to the correlation of Fig. 5.

Both the top 10 farms with an annual milk income of >6000 euro/ha and the top 10 farms with a rent charge of PG of >750 euro/ha were all located in the Netherlands.

4.2 Main product productivity

For specialised dairy farms, producing milk is their main business, and milk income is closely correlated to milk production (Fig. 6). The high coefficient of determination (R^2) of the linear regression in Fig. 6 indicates that differences in milk selling price between countries (Annex 2) did not significantly impact the income from milk relative to the production of milk.

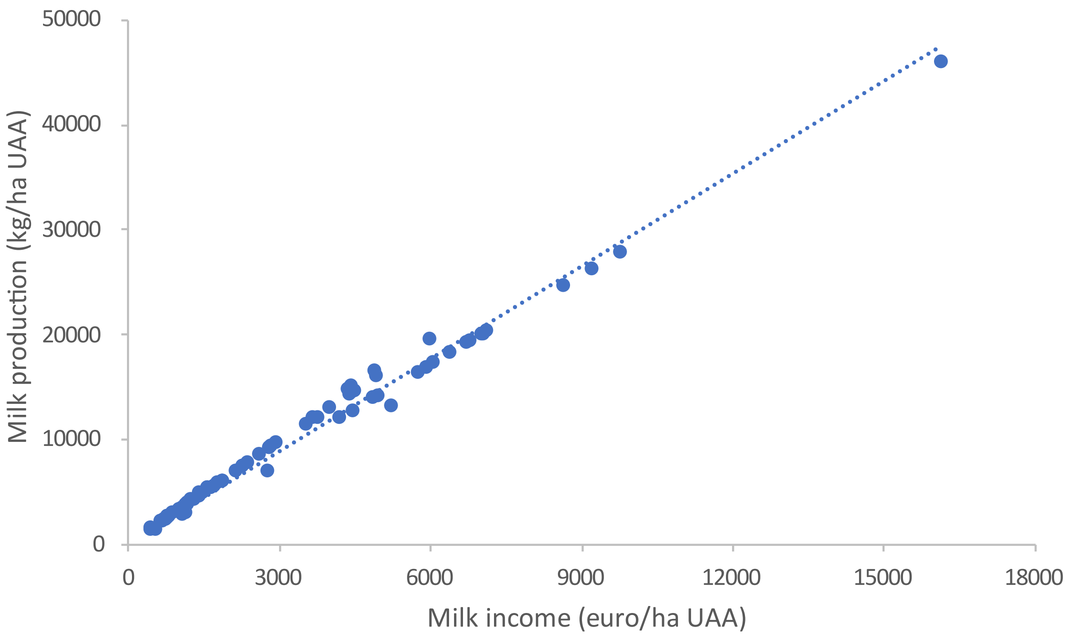

Figure 6. Correlation between annual milk production per ha (y) and annual milk income (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.995; n=70):

$$y = 2.94 * x \quad (2)$$

The inverse of the slope of eqn. 2 (2.94) equals 0.34 euro/kg milk, which is the weighted average milk price for the specialised dairy farms in the survey. Their national milk selling price ranged from 0.30 to 0.40 euro per kg milk.

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The farm with the highest milk production (*c.* 45,000 kg/ha) was located in the Netherlands, but is not represented in Fig. 5 because no value for the rent charge of PG was supplied.

4.3 Stocking rate and production per animal

For the specialised dairy farms surveyed in 2019, both the milking cows stocking rate and the annual milk production per cow were positively correlated with milk production per ha, as is shown in Fig. 7 and 8.

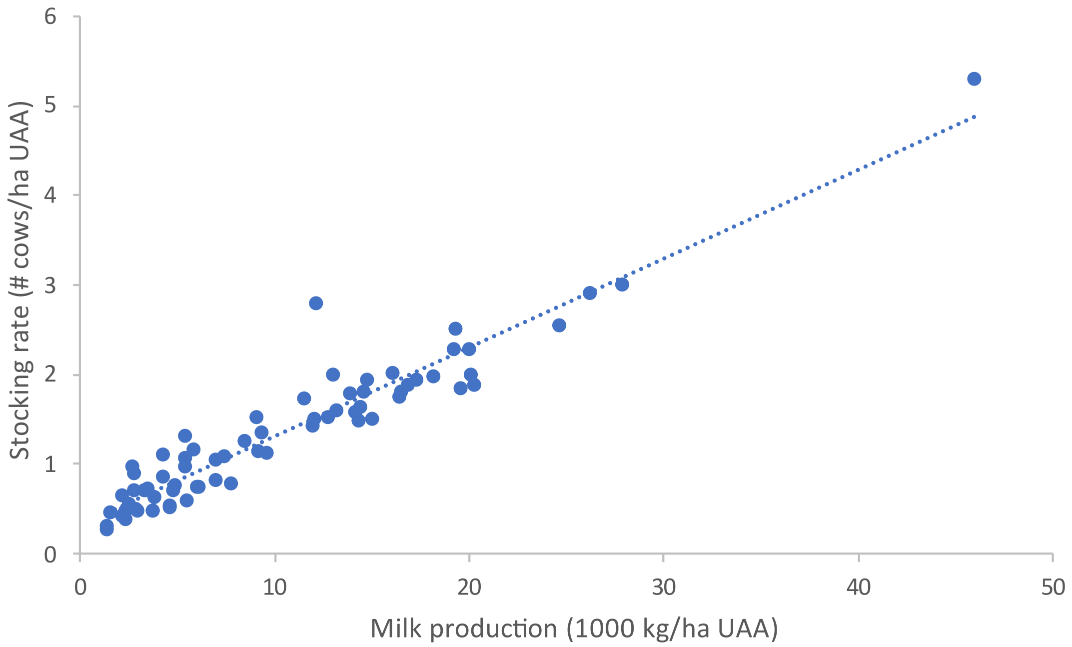

Figure 7. Correlation between stocking rate (y) and annual milk production per ha (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.91; n=70):

$y = 0.0991 * x + 0.313$ (3)

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The farm with the highest stocking density (>5 cows/ha) also produced the highest amount of milk per ha (*c*. 45,000 kg/ha). An outlier in Fig. 7 with a stocking rate of 2.8 cows/ha while producing 'only' 12,000 kg milk/ha is also visible in Fig. 8 with a relatively low milk production per cow of 4,300 kg. Generally, data points that are above the linear line in Fig. 7 are below the curvilinear line in Fig 8, because the milk production per ha is calculated by multiplying the stocking rate by milk production per cow.

The correlation between annual milk production per cow and milk production per ha could best be described by a curvilinear relation (Fig. 8) which corresponds with the natural constraints in milk production per cow.

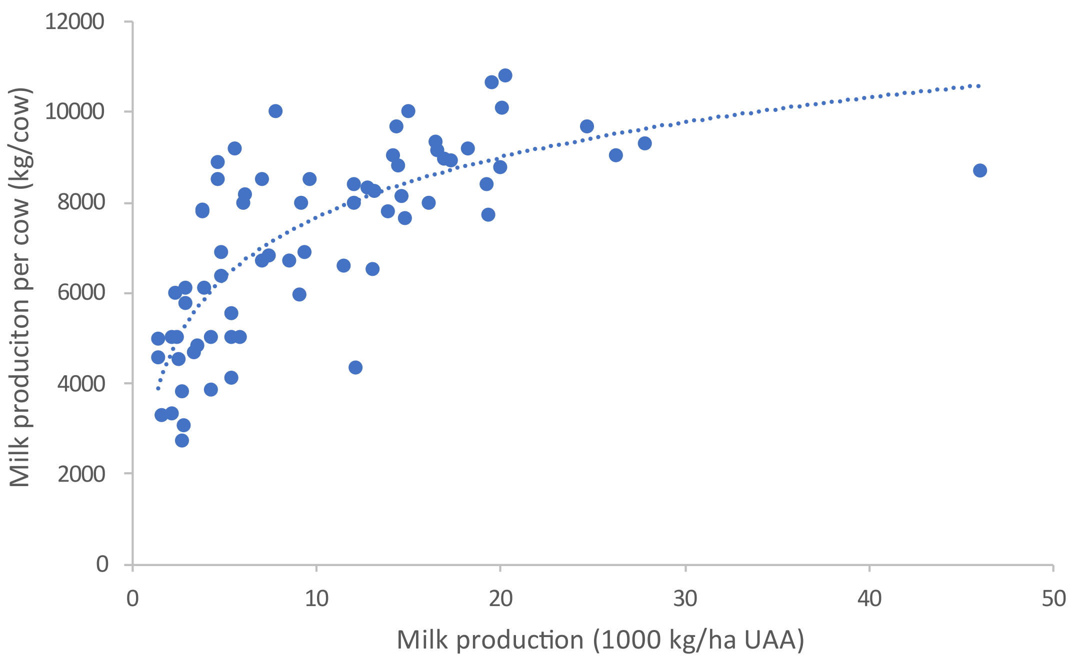

Figure 8. Correlation between annual milk production per cow (y) and annual milk production per ha (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.59; n=70):

$y = 1909 * \ln(x) + 3282$ (4)

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4.4 Imported feed and PG grass production

Producing milk requires feed which can be produced on-farm, e.g. from PG, and/or off-farm, i.e. purchased or imported feed. Fig. 9 illustrates a positive correlation between imported (or purchased) feed and milk production, where both are expressed per ha total farmed area.

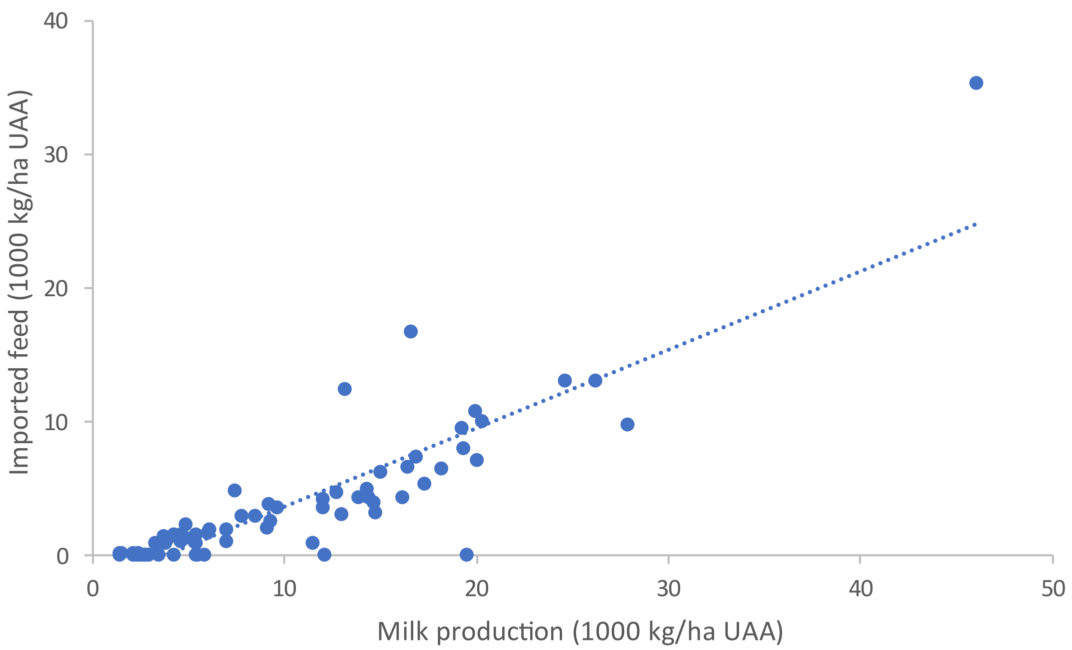

Figure 9. Correlation between annual total of imported feed per ha (y) and annual milk production per ha (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.75; n=70):

$$y = 0.584 * x - 2.16 \quad (5)$$

Total imported (or purchased) feed is calculated as the sum of the reported mass of up to five different feed types imported onto the farm. The farm in the Netherlands with the highest milk production per ha is also characterised by the highest amount of imported feed per ha. The other two outliers above the regression line with a relatively high feed import per ha were located in Slovenia (both imported feed and milk

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production close to 17,000 kg/ha) and Italy (both imported feed and milk production close to 13,000 kg/ha).

The two outliers below the regression line with zero feed import per ha were located in the UK (with almost 20,000 kg milk per ha) and in France (with 12,000 kg milk per ha). Without these five outliers, the regression equation would be $y = 0.459 * x - 1.18$ (R^2 = 0.88; n=65).

A positive correlation is also expected between the PG grass production (per ha PG) and milk production (Fig. 10). The annual PG grass production is based on values for grazing and cutting and for improved and unimproved PG, as supplied in the survey, and were combined with the estimated area shares of grazing and cutting in the (un)improved PG. Fig. 10 displays only 13 different values of PG grass production because farmers in the survey were requested to report these values in the following ranges: 0–5, 5–10, 10–15 and >15 tonnes of dry matter (DM)/ha. Due to averaging values from grazed and cut and from improved and unimproved PG, a total of 13 different (unique) values were obtained from the survey.

Two regressions were performed: one on all 62 data (Fig. 10) and one on the 13 ‘unique’ PG dry matter yield values (Fig 11). Curvilinear relations gave the best fit but were also selected because grassland productivity has natural constraints which limit maximum production values, e.g. depending on climatic conditions. In Fig. 11, two regression lines are illustrated that follow a similar trend, especially for most of the farms with milk production close to or below 20,000 kg/ha.

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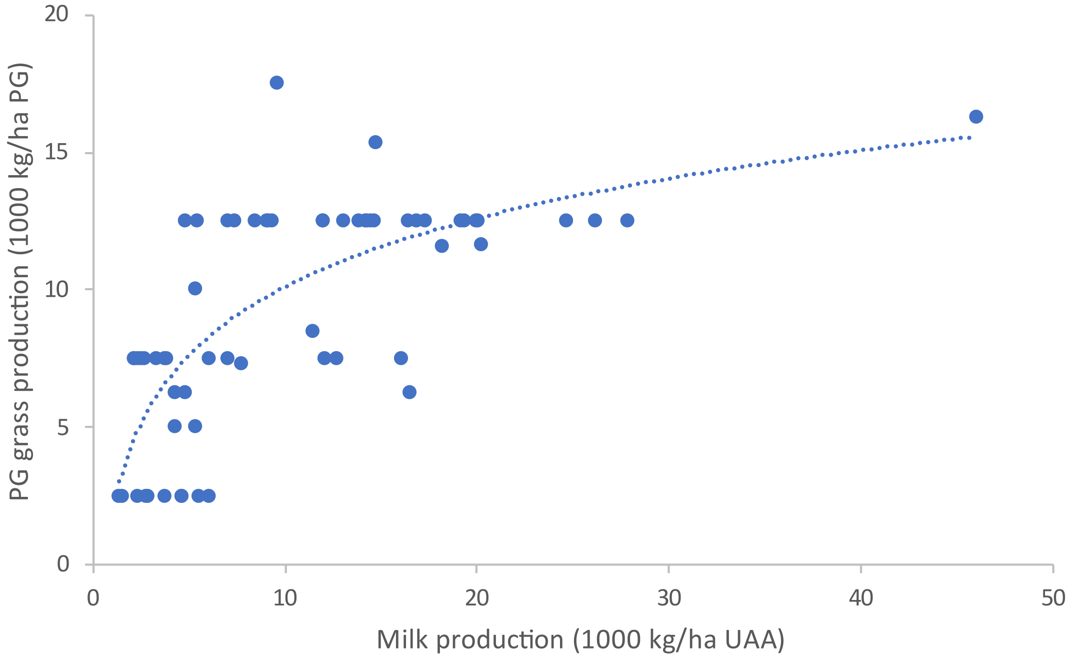

Figure 10. Correlation between annual PG grass dry matter production (y) and annual milk production per ha (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.51; n=62):

$$y = 3.58 * \ln(x) + 1.87 \quad (6)$$

The highest PG productivity (17.5 tonnes grass dry matter/ha) came from a farm located in the UK, while the second highest (16.3 tonnes grass dry matter/ha) was reported by the farm in the Netherlands with the highest milk production.

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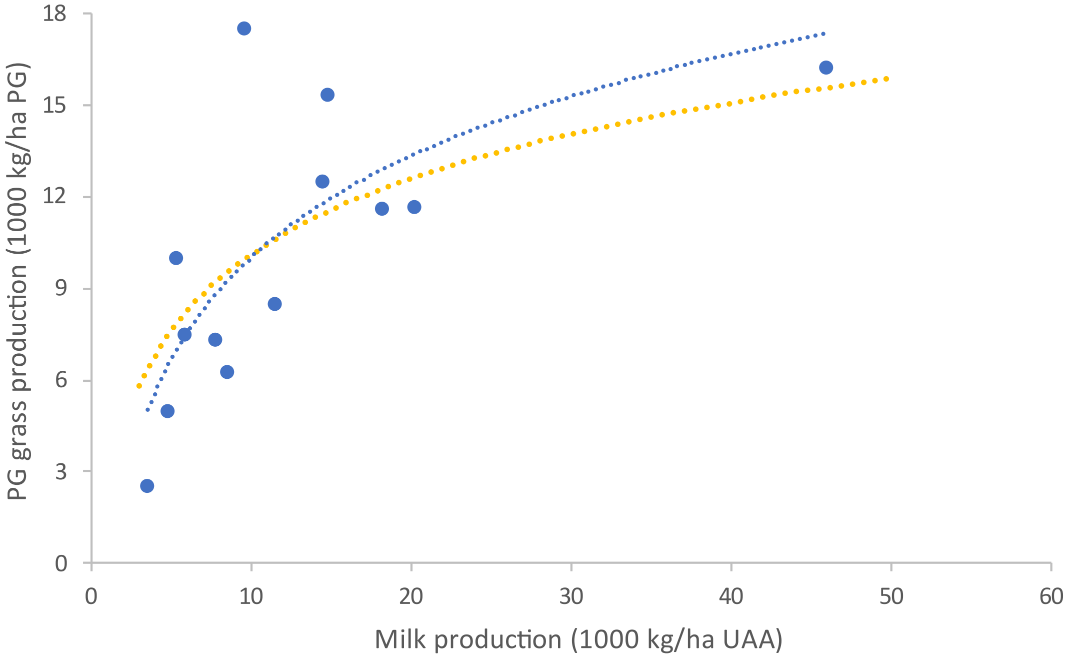

Figure 11. Correlation between annual PG grass dry matter production (y) and annual milk production per ha (x) on specialised dairy farms from the 2019 survey. The orange line refers to the regression equation of Figure 10, based on all individual data points. The blue line is based on average y-values per x-value (see text for explanation).

Regression equation (R^2 = 0.55; n=13):

$$y = 4.80 * \ln(x) - 1.04 \quad (7)$$

4.5 Manufactured N fertiliser input per ha

Manufactured N fertiliser rate was calculated from the responses in the survey based on separate values for grazing, silage and hay production on improved PG and their estimated area shares relative to total improved PG. Higher PG grass production per ha requires greater N input/supply and this was partly visible in the positive correlation between manufactured N fertiliser rate on PG and PG grass production (Fig. 12).

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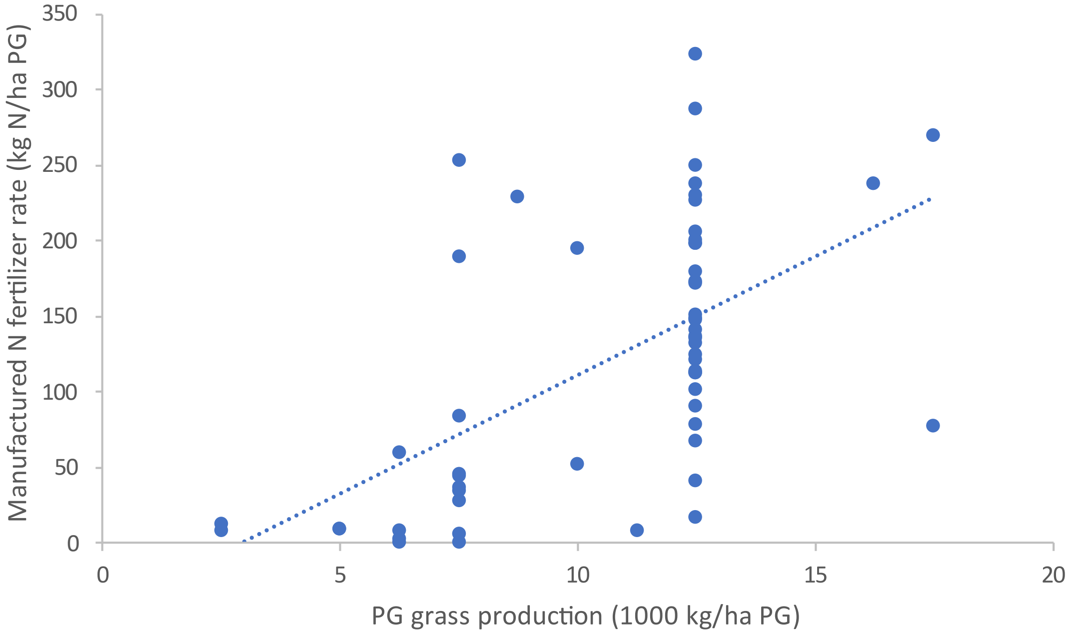

Figure 12. Correlation between annual application of manufactured N fertiliser (y) and annual PG grass dry matter production per ha (x), both on improved PG, on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.34; n=56):

$$y = 15.7 * x - 46.3 \quad (8)$$

Almost two thirds of the variation in manufactured N fertiliser application was not explained by the linear relation in Fig. 12. Part of that may be caused by the 'rough' estimation of the PG yields in 5 tonne (t) increments (see above), but considerable differences still remain in the dataset, e.g. an application of 78 kg N/ha for a yield >15 t/ha versus an application of *c*. 250 kg N/ha for a yield ranging between 5 and 10 t/ha. Moreover, the N application for yields between 10 and 15 t/ha, most of which are represented by the average of 12.5 t/ha, ranges from a low value of 17 to the highest value of 323 kg N/ha in the dataset. Local differences in summer rainfall, soil type, clover content and application of organic manures, may partly explain these differences.

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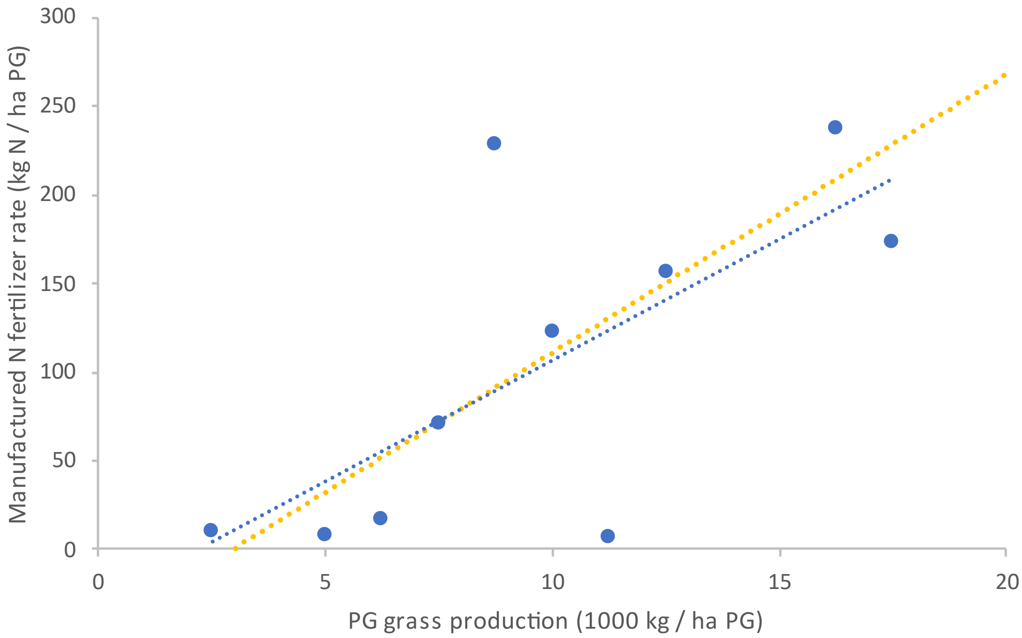

Figure 13. Correlation between annual application of manufactured N fertiliser (y) and annual PG grass dry matter production per ha (x), both on improved PG, on specialised dairy farms from the 2019 survey. The orange line refers to the regression equation of Figure 12, based on all individual data points. The blue line is based on average y-values per x-value, see below.

Regression equation (R^2 = 0.49; n=10):

$y = 13.6 * x - 29.1$ (9)

Similar to Fig. 10 & 11, two regressions were performed: one on all 56 data (Fig. 12) and one on the 10 'unique' PG dry matter yield values (Fig. 13), which (again) show quite similar trends between 3 and 18 t DM/ha. Two outliers have a relatively large impact on the R^2 in the correlation of Fig. 13, viz. a farm with a PG yield of almost 9 t DM/ha and a fertiliser application rate of 230 kg N/ha (located in the UK) and a farm with a PG yield of *c*. 11 t DM/ha and a fertiliser application rate of <10 kg N/ha (located in Slovenia). Without these two farms, the R^2 increases from 0.49 in eqn. 9 (n=10) to 0.84 (n=8) with the equation: $y = 1.02*(x)^{1.89}$.

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To test whether improvement in the correlation is possible, manufactured N fertiliser rate has also been regressed against milk production per ha (Fig. 14). This correlation only shows a small improvement in R^2 compared to the correlation with PG yield (0.37 versus 0.34 in Fig. 12). A large variation is visible, e.g. within the range of 10,000 and 20,000 kg milk/ha, with a maximum of almost 325 kg N/ha at 14,000 kg milk/ha (farm in the UK) and a minimum of 0 kg N/ha at 13,000 kg milk/ha (farm in Italy).

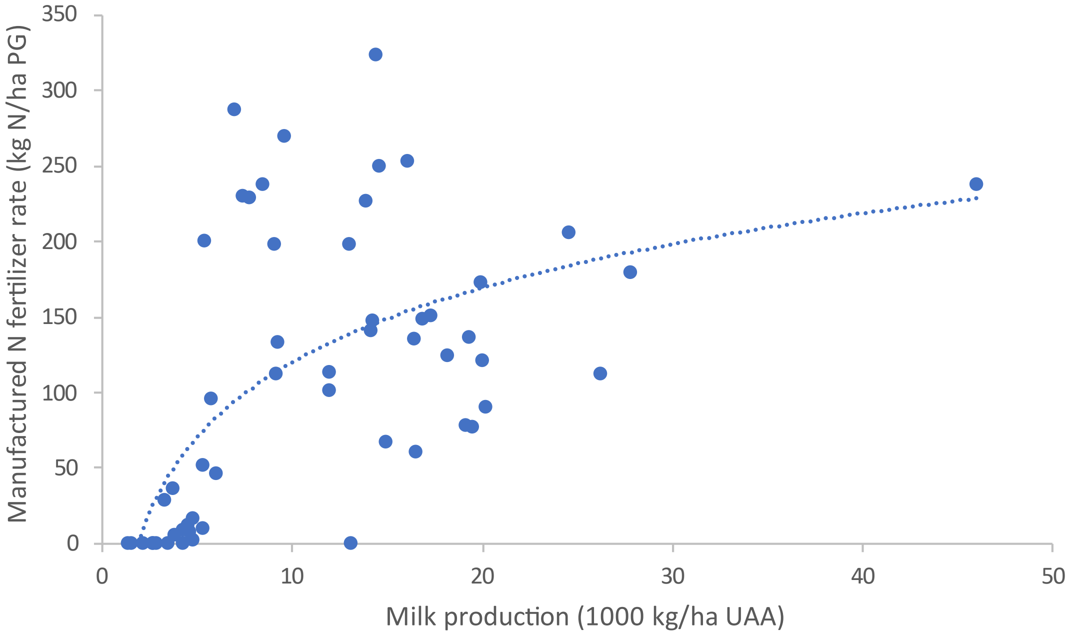

Figure 14. Correlation between annual application of manufactured N fertiliser on PG improved (y) and annual milk production per ha (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.37; n=55):

$$y = 71.2 * \ln(x) - 43.7 \quad (10)$$

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Combining PG yield and milk production in a multiple linear regression can explain 47% of the variation in manufactured N fertiliser application rate. Fig. 15 shows the results with the calculated N fertiliser application rate based on the regression results on the X-axis and the value from the survey on the Y-axis. Adding imported feed per ha UAA does not significantly improve the correlation (eqn. 10) because imported feed and milk production were reasonably well correlated (see Fig. 9 with R^2 = 0.75). With milk production in eqn. 10, the effect of imported feed on the N fertiliser application rate is included.

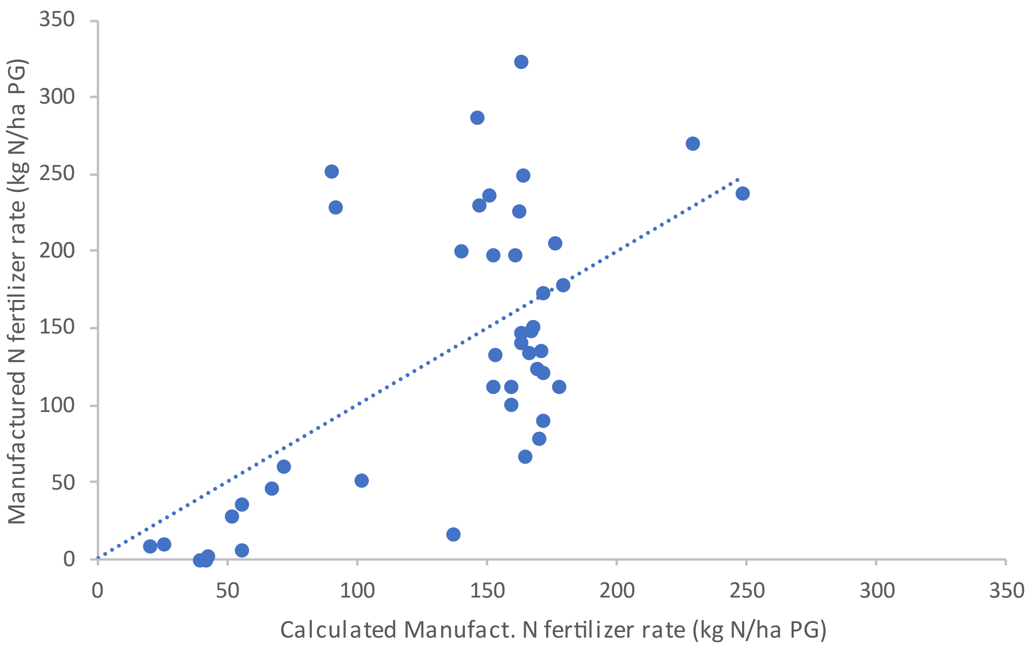

Figure 15. Correlation between annual application of manufactured N fertiliser on PG improved (y) and the calculated value for the application (x) on specialised dairy farms from the 2019 survey. The dotted line represents y=x.

Regression equation for the calculated N application on the X-axis (R^2 = 0.47; n=46):

$$x = -90.6 + 15.2 * \textit{PG-yield} + 24.1 * \ln(\textit{milk-production}) \quad (11)$$

(PG-yield and milk-production are the x-variables of resp. Fig. 12 and Fig. 14)

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4.6 Plant species diversity

Multi-species swards are one of the options to support biodiversity and pollination on dairy farms. Francksen et al. (2022) analysed experiments with different N rates including a zero treatment (control) and found a linear relationship between fertiliser N rate and the difference in plant species diversity between the control and the N application treatments (average decline of 1.5 species per 100 kg N/ha applied). In Fig. 16, the correlation between number of plant species found in PG improved and manufactured N fertiliser rate on PG suggests a decrease of 2.1 plant species per 100 kg N fertiliser rate, which is comparable to the value of Francksen et al. (2022).

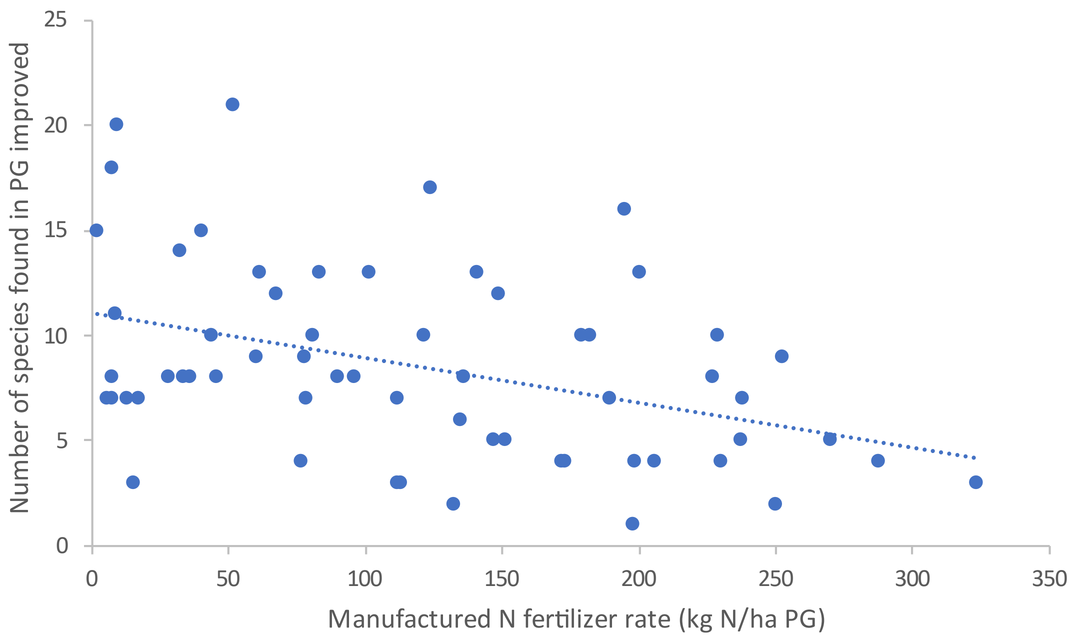

Figure 16. Correlation between number of plant species found in PG improved (y) and the annual application of manufactured N fertiliser on PG improved (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.16; n=61):

$$y = -0.0214 * x + 11.1 \quad (12)$$

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The negative relation (eqn. 11) is significant (-0.0214, s.e. = 0.0064, p-value = 0.0014), but still a large part (0.84) of the variation in the number of plant species remains unexplained.

In the 2019 survey, the number of plant species was also reported for unimproved PG, which was assumed to be unfertilized with respect to manufactured N fertiliser. Based on the correlation in Fig. 16, higher plant species diversity could be expected in unimproved PG relative to improved PG on the same farm. This was not the case for the selected specialised dairy farms of the 2019 survey (Fig. 17). In most situations where the number of plant species was reported in both improved and unimproved PG, this number was lower in unimproved compared to improved PG (see values below the dotted line in Fig. 17).

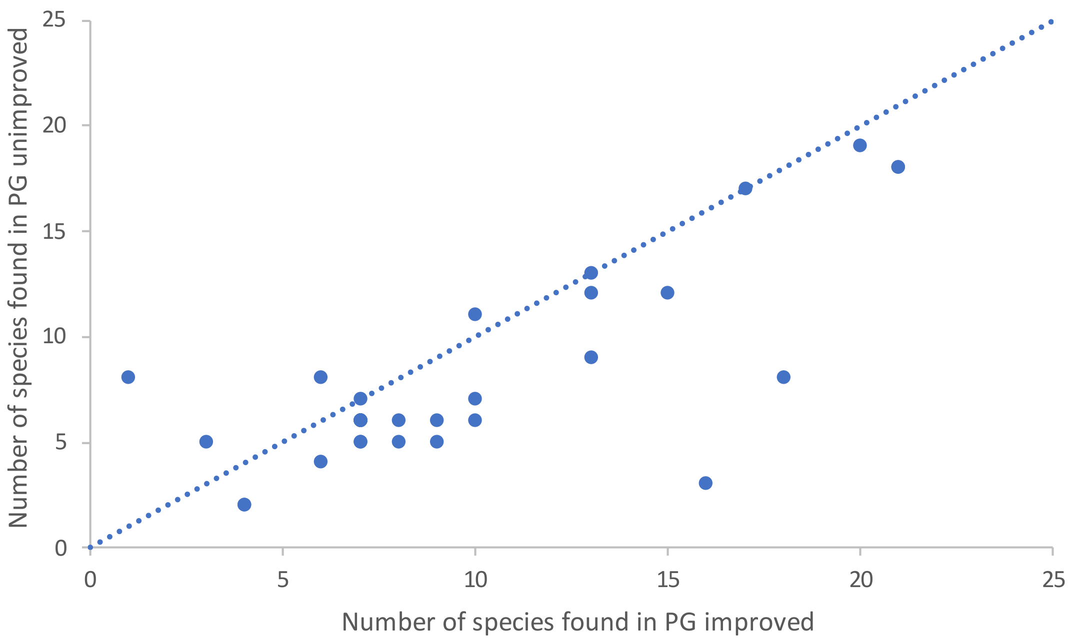

Figure 17. Correlation between number of plant species found in PG unimproved (y) and number of plant species found in PG improved (x) on specialised dairy farms from the 2019 survey (n =34). The dotted line represents y=x.

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4.7 Required feed at farm level

In section 4.4, correlations were analysed with respect to purchased feed and PG grass production per ha. This section explores the availability and correlations of these variables expressed as annual totals at farm level, where it is assumed that these two were the main two sources for feeding the dairy herd on specialised dairy farms. The correlation between imported feed and milk production, both at farm level, is illustrated in Fig. 18 and shows a positive linear correlation with four distinct outliers. The two farms with the highest milk production, viz. 3,500 tonne milk per farm have relatively low amounts of imported feed: one with almost zero feed imported and the other one with *c*. 300 tonnes of feed imported (both located in the UK). The two farms with the highest amount of feed imported, viz. 1,350 and almost 1,200 tonnes, are both located in the Netherlands and have milk productions of 1,750 and 2,160 tonnes at farm level. These four outliers may be errors in survey responses, but they could also be correct and deviate strongly from the majority of the farms in the survey. When all data are included, the regression equation would be $y = 0.256 * x + 57.7$ ($R^2 = 0.45$; n=62). However, the orange data point in Fig. 18 has been excluded because it has a relatively large effect on the equation, unlike the other three.

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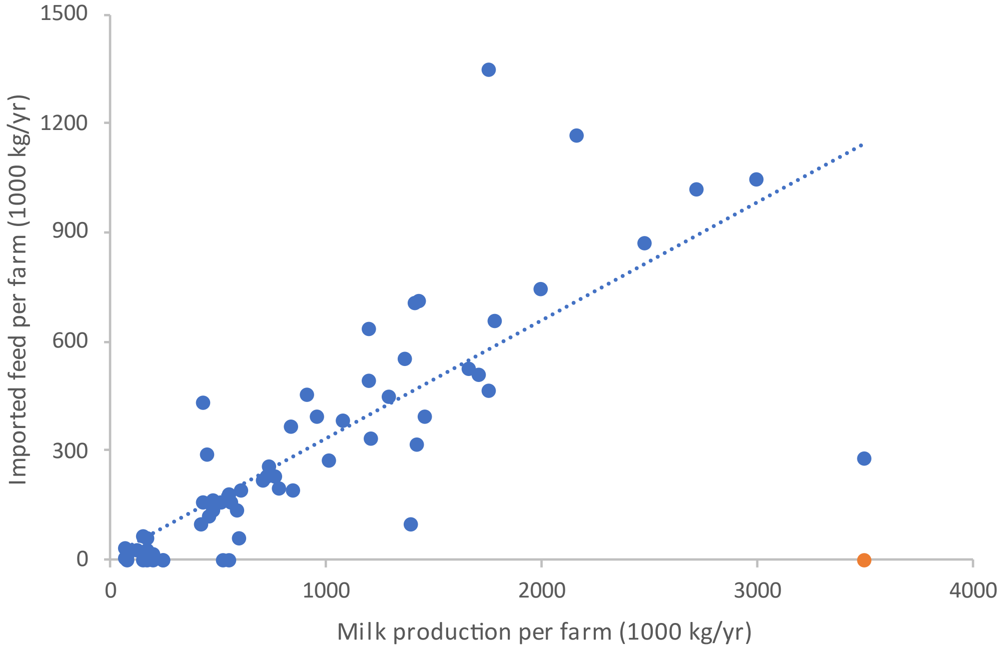

Figure 18. Correlation between annual total of imported (purchased) feed at farm level (y) and annual milk production at farm level (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.63; n=61, excluding the orange data point):

$y = 0.325 * x + 9.09$ (13)

Also, in the correlation between PG grass production and milk production, both at farm level, outliers occur, viz. two with the highest amount of grass production (Fig. 19). One of the two farms produced a relatively large amount of grass at farm level (almost 7,500 tonnes dry matter) and is the same farm that had no feed import in Fig. 18. The other one in Fig. 19 with a grass production of *c*. 4,300 tonnes is also located in the UK and had a milk production of 2,700 tonnes milk per year. For consistency reasons, the outlier with almost 7,500 tonnes PG grass production was also excluded in the regression of Fig. 19. Including this data point would give the following equation: $y = 0.983 * x – 77.1$ (R^2 = 0.55; n=62).

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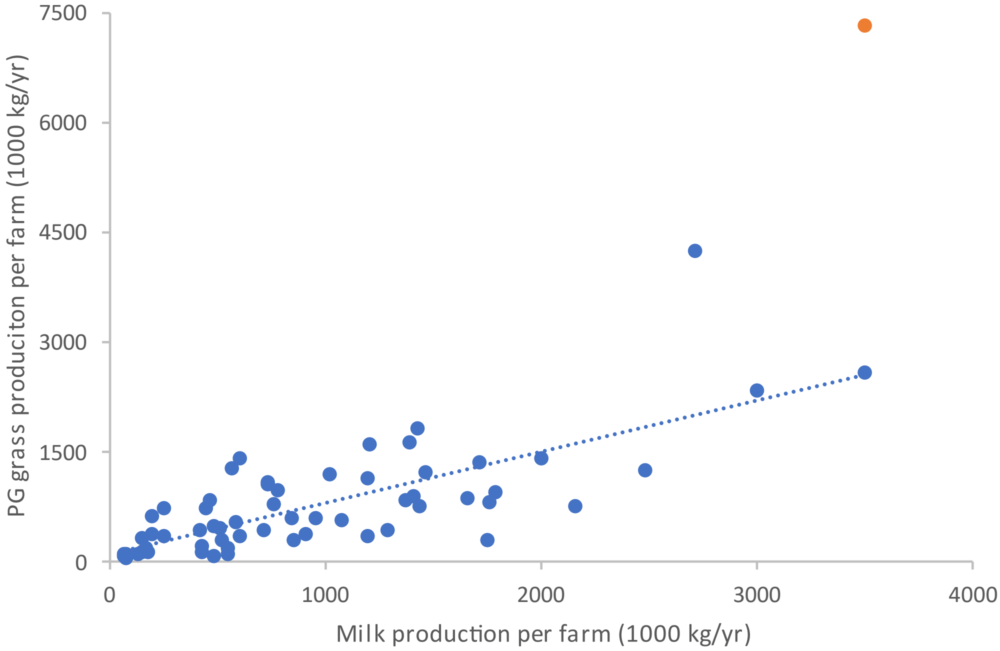

Figure 19. Correlation between annual PG grass dry matter production at farm level (y) and annual milk production at farm level (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.56; n=61, excluding the orange data point):

$$y = 0.697 * x - 126 \quad (14)$$

In Fig. 20 both PG grass production and total imported (i.e. purchased) feed were combined in a multiple linear regression to calculate the milk production at farm level. This equation and its correlation with the milk production from the 2019 survey (R^2 of 0.84) illustrates how milk production depends on the availability of PG grass and imported feed.

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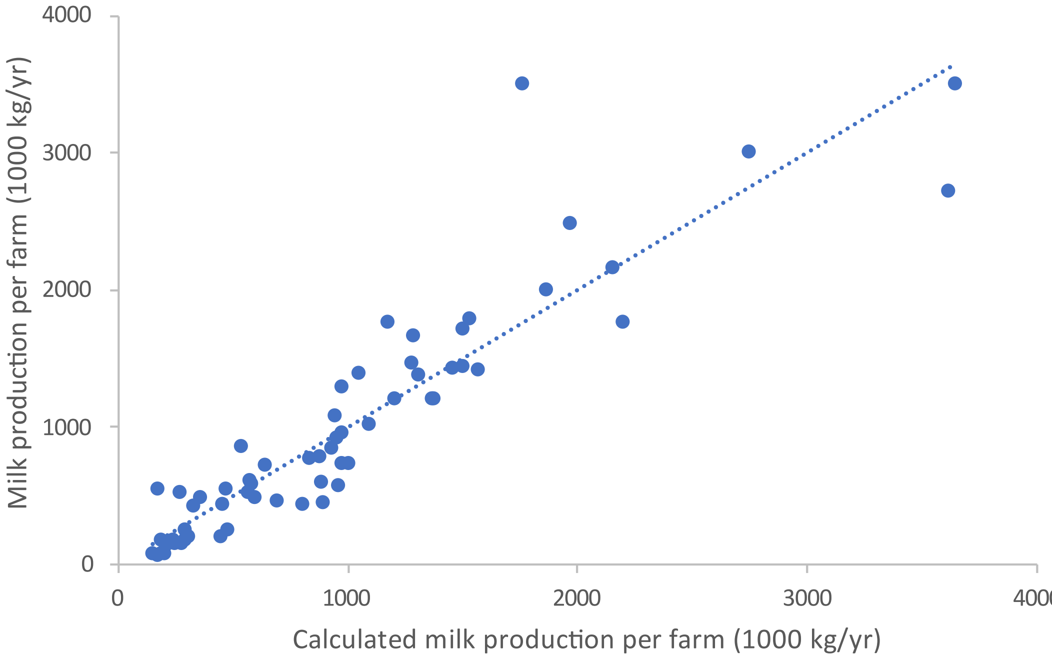

Figure 20. Correlation between annual milk production at farm level (y) and the calculated value for the annual milk production (x) on specialised dairy farms from the 2019 survey. The dotted line represents y=x.

Regression equation for the calculated annual milk production at farm level on the X-axis (R^2 = 0.84; n=62):

x = 110 + 0.481 * *PG-grass-production* + 1.44 * *imported-feed* (15)

(PG-grass-production and imported-feed are the y-variables of resp. Fig. 19 and Fig. 18)

When the regression is forced though the origin (if both PG-grass production and imported feed are zero, no milk production is assumed), then the equation reads:

x = 0.508 * *PG-grass-production* + 1.56 * *imported-feed* (15a)

Equations 15 and 15a suggest that corrected for the impact of imported feed, the PG forage value was circa 0.5 kg milk per kg of grass dry matter and that corrected for the impact of PG grass, the forage value of imported feed equaled 1.5 kg milk per kg imported feed (as purchased).

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The main activity of a specialised dairy farm is the conversion of feed into milk, with varying proportions of home-grown grass and imported feed. At a given level of milk production, the required feed can either be produced at the farm or can be imported from outside the farm. In Fig. 21 this trade-off is illustrated by the (dotted) iso-lines. Each iso-line represents a certain milk production (in million kg milk per farm) and the line depicts the relation between the amounts of PG grass dry matter (x-axis) and imported feed (y-axis) that are needed for this milk production level. The iso-lines are based on eqn. 15, in which x stands for the calculated milk production. In Fig. 21, the data points of the specialised dairy farms have also been plotted, but their milk production could not be visualised in this figure.

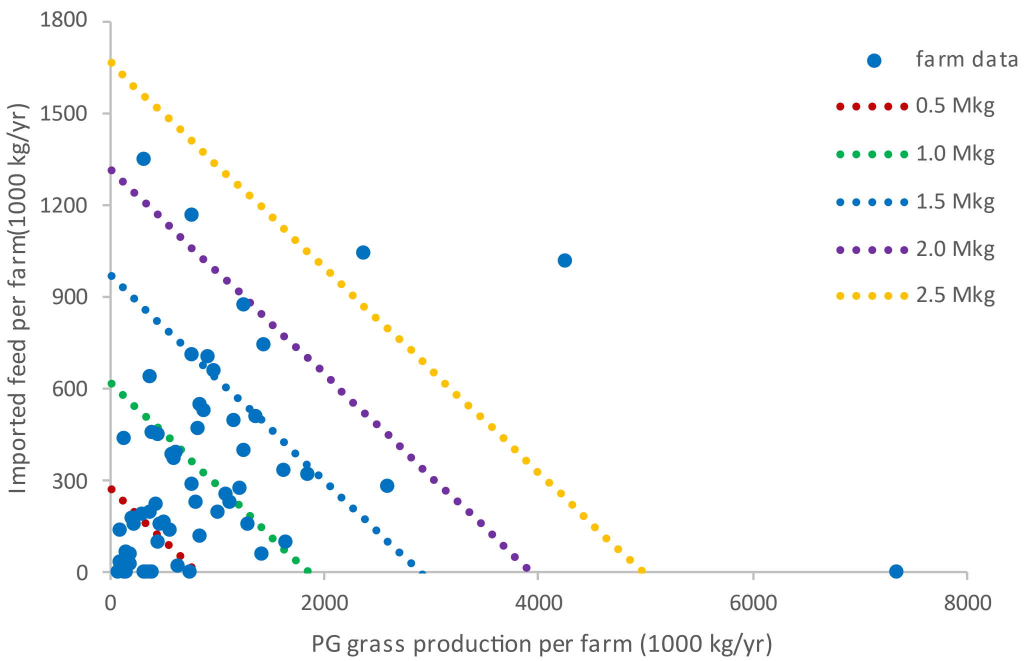

Figure 21. Illustration of different combinations of annual PG grass dry matter production and imported feed, both at farm level, on specialised dairy farms from the 2019 survey (n = 62). The dotted lines represent iso-lines of equal milk production levels and were calculated with eqn. 15 (see text for further explanation).

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In addition to the dependency of milk production on various combinations of PG grass and imported feed at farm level (illustrated in Fig. 21), the ratio between the two, viz. imported feed divided by PG grass (kg/kg), appears reasonably correlated with milk production intensity per ha (Fig. 22). This correlation illustrates that for higher milk production per ha, generally more feed is imported relative to the on-farm PG grass dry matter production, which could be explained by the limitations of producing grass per ha and the higher total feed requirement when more milk is produced per ha.

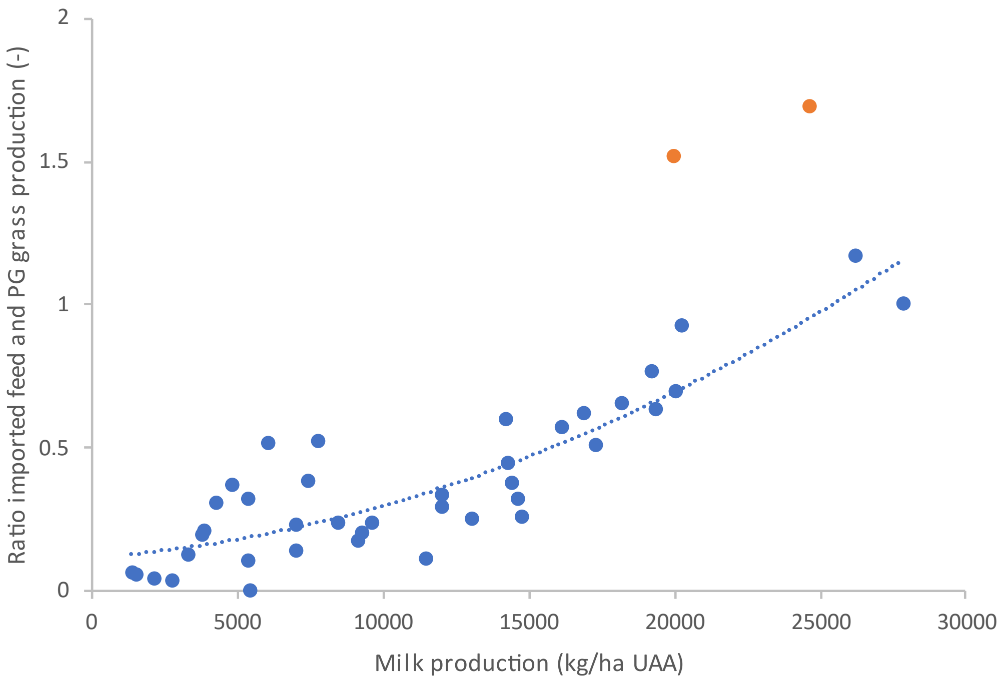

Figure 22. Correlation between the ratio (y) of imported feed per farm and produced grass from PG per farm and annual milk production per ha (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.78; n=40, excluding the two orange data points):

$$y = 1.35*10^{-9} * x^2 + 0.153 \quad (16)$$

Including the two outliers in Fig. 22 would give the following equation:

$y = 1.66*10^{-9} * x^2 + 0.132$ (R^2 = 0.72; n=42).

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4.8 Manufactured N fertiliser input per farm

Also, for manufactured N fertiliser use, correlations were investigated at farm level as an additional option next to the correlations per ha (compare with section 4.5). The first correlation with milk production per farm shows a curvilinear relation with one distinct outlier. This is a farm in the UK with a milk production of 6,700 tonnes and a N fertiliser input on PG of only 17 tonnes N. This farm was not visible in Fig. 18 and 19 because it was excluded due to missing data with respect to PG grass yield.

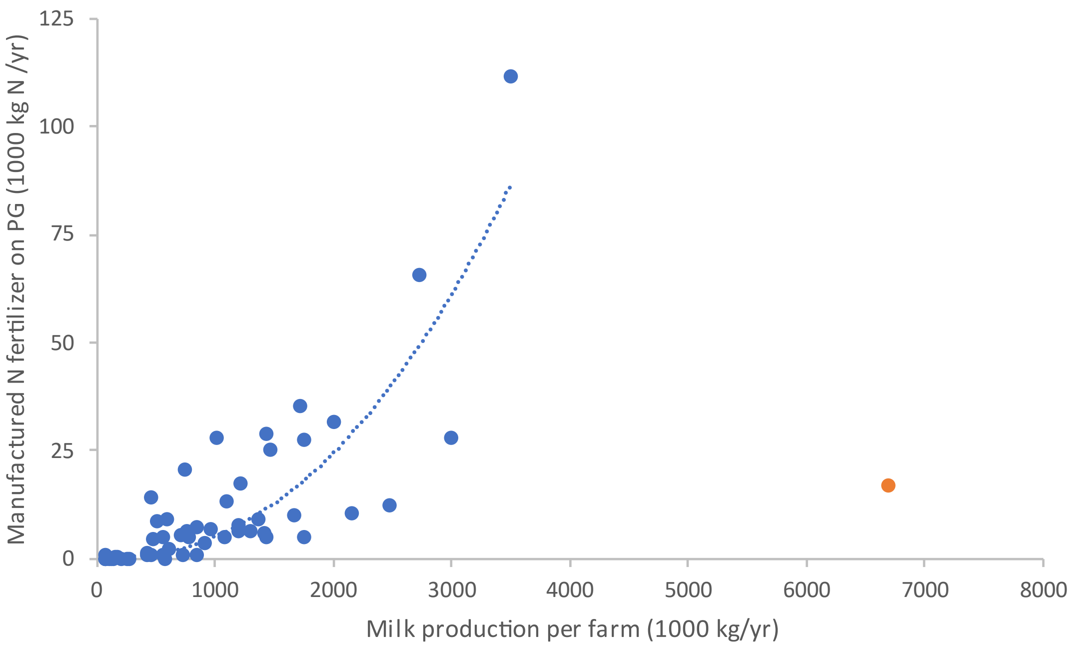

Figure 23. Correlation between application of manufactured N fertiliser on PG improved at farm level (y) and annual milk production per farm (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.70; n=54, excluding the orange dot):

$y = 8.44*10^{-7} * x^{2.26}$ (17)

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The second correlation with PG grass production per farm is best described by a linear function and explains most of the variation in PG fertiliser use at farm level with an R^2 of 0.90 (eqn. 18), although at PG grass production levels of less than 1,500 tonnes, the variation in manufactured N fertiliser input on PG was relatively high (Fig. 24).

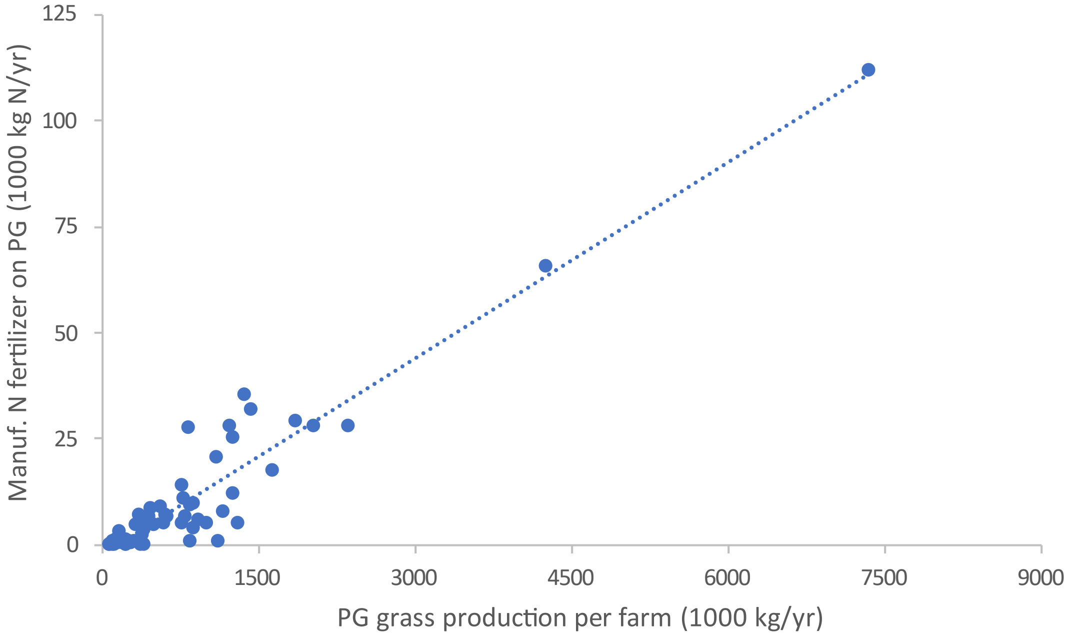

Figure 24. Correlation between application of manufactured N fertiliser on PG improved at farm level (y) and the total PG grass dry matter production per farm (x) on specialised dairy farms from the 2019 survey.

Regression equation (R^2 = 0.90; n=58):

$$y = 0.0154 * x - 2.34 \quad (18)$$

When the regression is forced though the origin (if PG-grass production is zero, no fertilizer application on PG is assumed), then the equation reads:

$$y = 0.0144 * x \quad (18a)$$

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5. Synthesis modelling

The regression equations of sections 4.1 – 4.8 have been combined into a model to calculate a number of indicators for ecosystem services (ESS) delivered by specialised dairy farms in Europe. Alongside some general indicators, a number of indicators identified in Newell Price (2020) were also simulated. Due to limitations of both the data in the survey and the quantitative correlation analysis, only a sub-set of the indicators identified by Newell Price, as the top five highest ranked per ESS for farmers and advisors, could be simulated. Some of the original indicators have been replaced by variables that are similar but not identical because data were not available to simulate the original indicators. This is the case for, e.g., '*Nitrogen use efficiency (fertiliser)*' which is not expressed as N input / N output. i.e. the original unit in Newell Price (2020), but as kg grass DM produced on PG / kg manufactured N fertiliser applied, and '*Botanical composition*' which is not expressed in % cover, but in number of plant species found in PG. Indicators for water quality (ESS 4 in Table 1), such as manure quantities, including total effective N input rate (two indicators identified for water quality) could not be analysed due to uncertainties in the original data of the 2019 survey. Also, indicators for landscape aesthetics & recreation (ESS 6 in Table 1) could not be simulated by correlations in this report.

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Table 1. Selected indicators that have been simulated by using the correlations of sections 4.1 – 4.8, including their corresponding code from Newell Price (2020). See text for explanation.

Indicator	ESS number	Newell Price	Figure
Stocking rate of milking cows	1	IND116	25
Milk production per cow	1	IND108	26
Milk production per farm	1		27
PG grass dry matter production	1	IND110	28
Forage efficiency of milk production	1	IND108	29
Nitrogen use efficiency (fertiliser)	1	IND111	30
Botanical composition	2	IND9	31
Stocking rate of ruminants	3, 5	IND19, IND85	32
Manufactured N fertiliser rate	3	IND20	33

Note: ESS numbers refer to the following ESS: (1) food production, (2) biodiversity and pollination, (3) climate change, (4) water quality, (5) flood and erosion control, (6) landscape aesthetics & recreation.

The model requires the '*typical rent charge of PG in the area*' as an external input, which is assumed to be a proxy for production costs (as mentioned in section 4.1). Then, the model calculates a number of variables, expressed per ha, by using the equations which are described in sections 4.1 to 4.8. In this model the output of one equation is often used as input for the 'next' equation, which means that the outcomes of the model are only determined by the parameters of the equations (the described correlations between the specified variables) and the rent charge of PG. If a variable is required at farm level, also the farm size (e.g. total farmed area in UAA) needs to be supplied as an external input. Farm sizes were variable in the specialised dairy farms dataset without a clear relation with other variables.

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Food production

The stocking rate of milking cows is calculated as a function of the PG rent charge by using eqn. 1, 2 and 3. Intermediate steps of this calculation are milk income (eqn. 1) and milk production (eqn. 2). Fig. 25 shows that the model (blue dotted line) produces a similar curve to the direct correlation between stocking rate and rent charge (red dotted line). The variation is still considerable, which is caused by the unexplained variation of eqn. 1 relating milk income to rent charge.

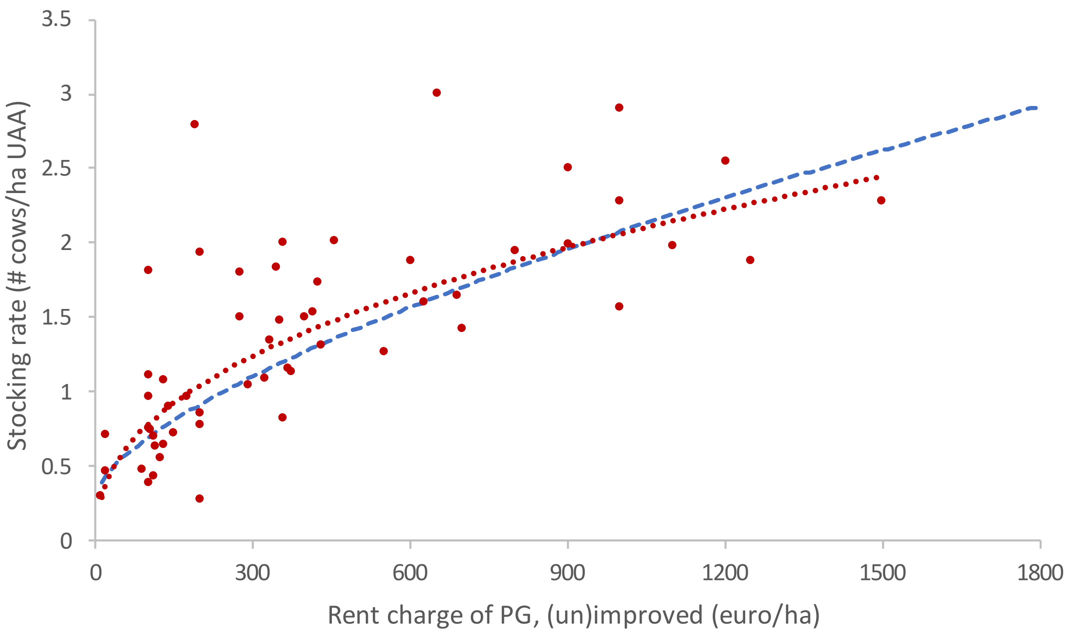

Figure 25. Milking cow stocking rate as a function of PG rent charge. Red dots are data points from the survey. The red dotted line results from a linear regression applied directly to the data and the blue dotted line has been calculated by applying eqn. 1, 2 and 3 (see sections above).

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The relationship between milk production per cow and PG rent charge is shown in Fig. 26. Here, milk production per cow is calculated by using eqn. 1, 2 and 4, again with milk income (eqn. 1) and milk production (eqn. 2) as intermediate steps. Similar to Fig. 25, Fig. 26 also shows that the model output (blue dotted line) is similar to a direct correlation between milk production per cow and rent charge (red dotted line). The variation is also considerable, mostly due to the unexplained variation associated with eqn. 1.

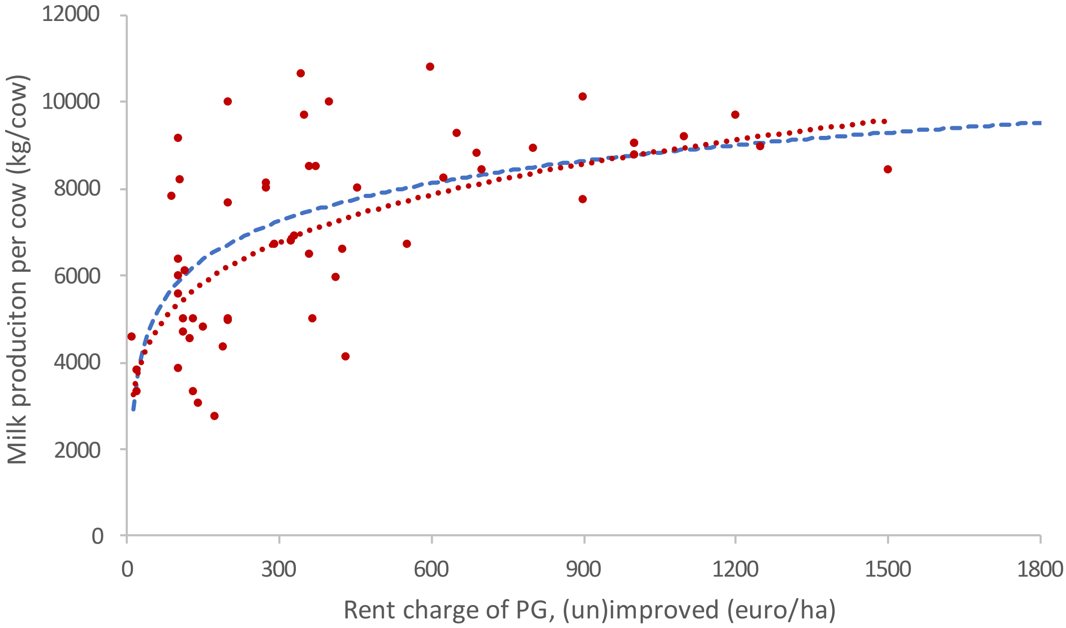

Figure 26. Milk production per cow as a function of PG rent charge. Red dots are data points from the survey. The red dotted line results from a linear regression applied directly to the data and the blue dotted line has been calculated by applying eqn. 1, 2 and 4 (see sections above).

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Milk production per ha of total farmed area is calculated by multiplying the stocking rate of milking cows (Fig. 25) by the milk production per cow (Fig. 27). The direct regression (red dotted line) and the calculated values (blue dotted line, based on eqn. 1, 2, 3 and 4) are almost identical (Fig. 27) with higher values of milk production per ha when more rent was charged for PG.

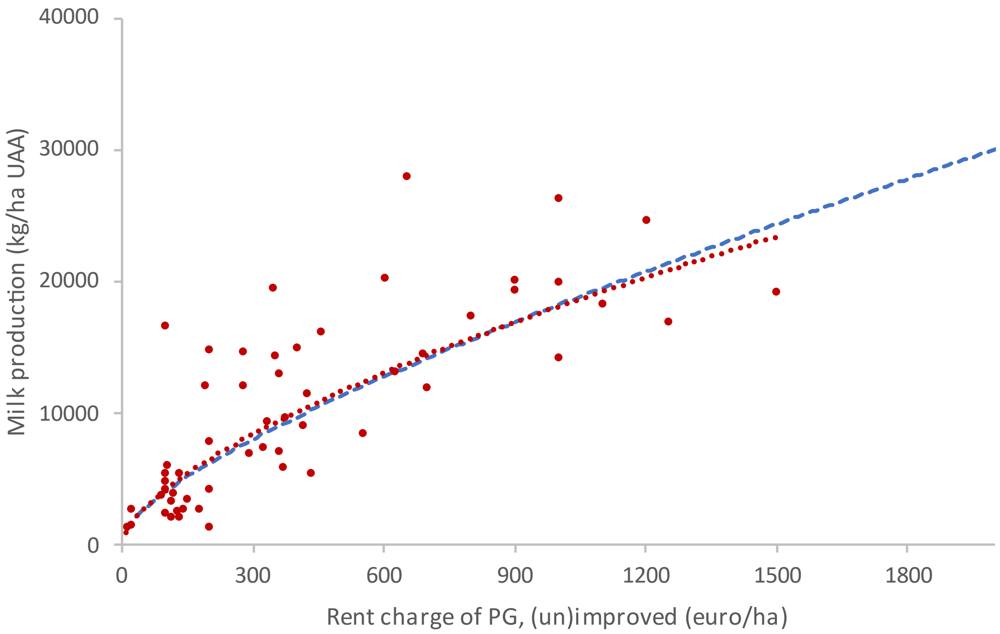

Figure 27. Milk production per ha as a function of PG rent charge. Red dots are data points from the survey. The red dotted line results from a linear regression applied directly to the data and the blue dotted line has been calculated by multiplying the calculated milking cows stocking rate (Fig. 25) by the calculated milk production per cow (Fig. 26).

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The PG grass dry matter production per ha is calculated by using two sets of equations that give different results (Fig. 28). The lower dotted blue line in Fig. 28 is calculated using milk production per ha based on Fig. 27 and eqn. 6. This result is based on variables that are expressed per ha (see eqn. 6). The second (higher) dotted blue line results from milk production per ha (Fig. 27) as input, combined with the ratio of PG area relative to total farmed area (average value of 0.84; section 3.2): eqn. 15a and eqn. 16. Eqn. 15a refers to variables expressed at farm level (both x and y) and therefore a value for farm size is needed in the calculation. The final outcome of this calculation was identical for farm sizes of 30 and 180 ha UAA, combined with the average ratio of PG area / total UAA, from which it was concluded that the result in Fig. 28 does not depend on farm size. The direct correlation (red dotted line in Fig. 28) falls in between the higher and lower calculated values and final estimates could be calculated by averaging both values.

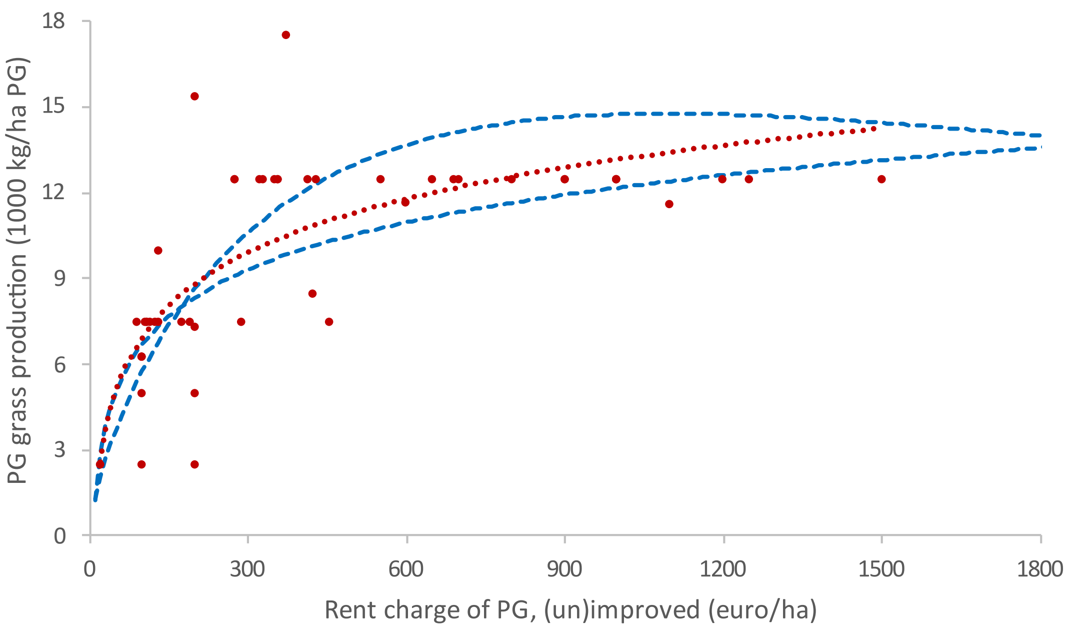

Figure 28. PG grass dry matter production per ha as a function of PG rent charge. Red dots are data points from the survey. The red dotted line results from a linear regression applied directly to the data and the blue dotted lines have been calculated by applying eqn. 6 (lower line) and a combination of eqn. 15a and 16 (higher line).

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Forage efficiency in this analysis is defined as the amount of milk (kg) that can be produced per kg of total feed. Total feed in this definition is expressed in fresh matter and calculated by the sum of imported (purchased) feed (assumed fresh matter) and the PG grass production (supplied in dry matter) divided by 0.2 (assumed dry matter fraction in PG grass). Finally, forage efficiency is calculated by using the milk production per ha (Fig. 27), also on the x-axis of Fig. 29, and the PG grass production per ha of Fig. 28 combined with eqn. 16. Again, a value for farm size is needed for the calculation, but the results in Fig. 29 do not depend on this farm size. The relation from the calculated results is similar to the direct correlation and illustrates that with higher milk production intensity per ha overall forage efficiency increases.

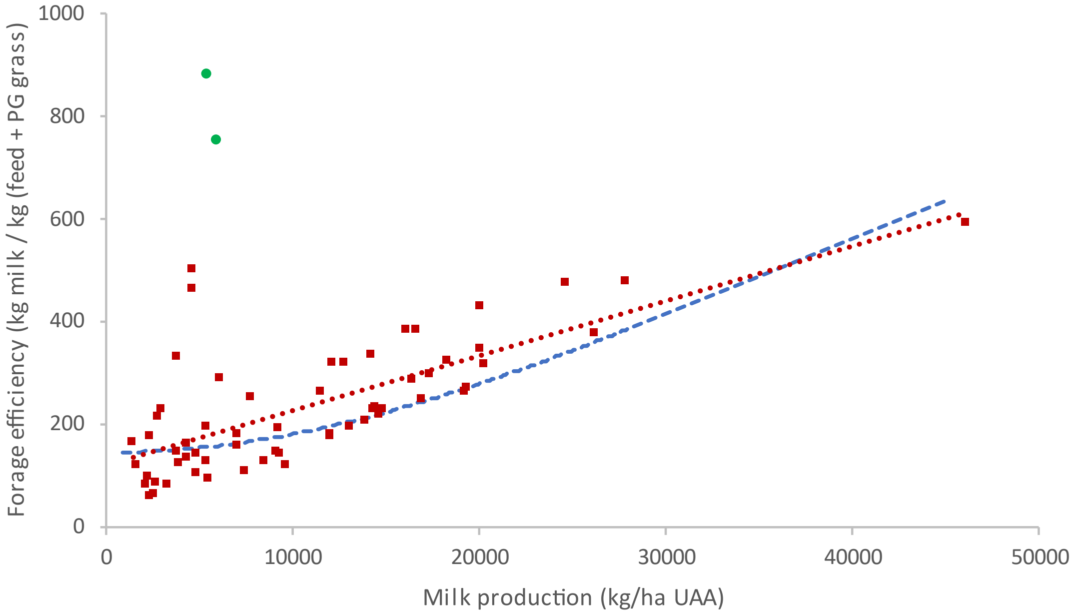

Figure 29. Forage efficiency, expressed as kg milk produced per kg imported feed + PG grass produced, as a function of milk production per ha. The red and two green dots are data points from the survey. The red dotted line results from a linear regression applied directly to the data (only the red data points; the two green ones were excluded from the regression), and the blue dotted line was calculated by applying eqn. 15a and 16.

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The fertiliser N use efficiency has been defined in this report by the quotient of produced grass dry matter on total PG area and total applied manufactured N fertiliser, both at farm level. This definition excludes the contribution of organic manures and biological fixation to increasing PG productivity which impacts the above defined fertiliser N efficiency. Indeed, ten data points, which have been excluded from Fig. 30, have extreme high N fertiliser efficiency values (ranging from 1,300 to 40,000 kg grass DM/kg N applied), due to their (very) low fertiliser N application rates (less than 10 kg N per ha PG, and in four farms less than 1 kg N/ha). These farms are less suited to analysing fertiliser use efficiency at farm level, because they hardly use manufactured N fertiliser and other sources of N for producing grass will potentially have a large impact on the efficiency value (such as purchased feed or abundant presence of clover species in PG). There are still four data points in Fig. 30 with relatively high efficiency values, viz. higher than 250 kg DM/kg N, again due to relatively low N fertiliser rates of mostly less than 10 kg N/ha. All farms with very high N fertiliser efficiency values (the ten excluded farms plus the four in Fig. 30) produced less than 5,500 kg milk/ha UAA (the average value for these 14 farms was 3,000 kg milk/ha UAA) and clearly represent low productivity farms in the dataset of selected specialised dairy farms from the survey. The other farms with efficiency values below 200 kg DM/kg N seem not well correlated with milk production per ha. This can also be concluded from the model calculations which were done in two different ways. A constant farm level efficiency of 69 kg DM/kg N results from the inverse of the slope of the equation in Fig. 18a, and combining eqn. 15a and 18a gives a comparable horizontal trend but with some higher and some lower values compared to the constant value. All three lines in Fig. 30 (red, green and blue) are similar for values of more than *c*. 10,000 kg milk/ha UAA.

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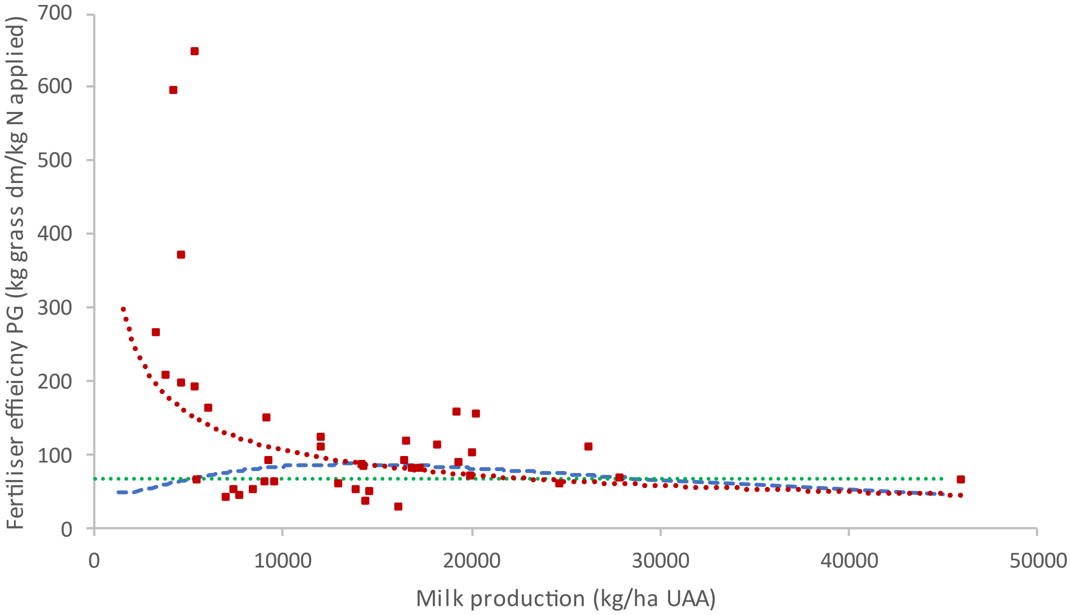

Figure 30. Manufactured N fertiliser efficiency on total PG, calculated from data at farm level, as a function of the milk production per ha. Red dots are data points from the survey (excluding 10 data points, see text for explanation). The red dotted line results from a linear regression applied directly to the data (excluding the 10 data points) and the blue dotted line was calculated by using eqn. 15a and 18a, with the green dotted line referring to a constant of 69.4 kg grass dry matter/kg N applied (inverse of the slope from Fig. 18a).

Biodiversity and pollination

The number of plant species found on improved PG does not correlate well with the milk production per ha, as illustrated both by the data points from the survey and the calculated results from the model (Fig. 31). Apparently, the scatter in Fig. 5 and 14, added to the correlation of Fig. 16, ‘masks’ a possible correlation between plant species diversity and milk production per ha. A better option would be to model the plant species diversity via the calculated manufactured N fertiliser rate (see Fig. 33a) and the correlation from Fig. 16.

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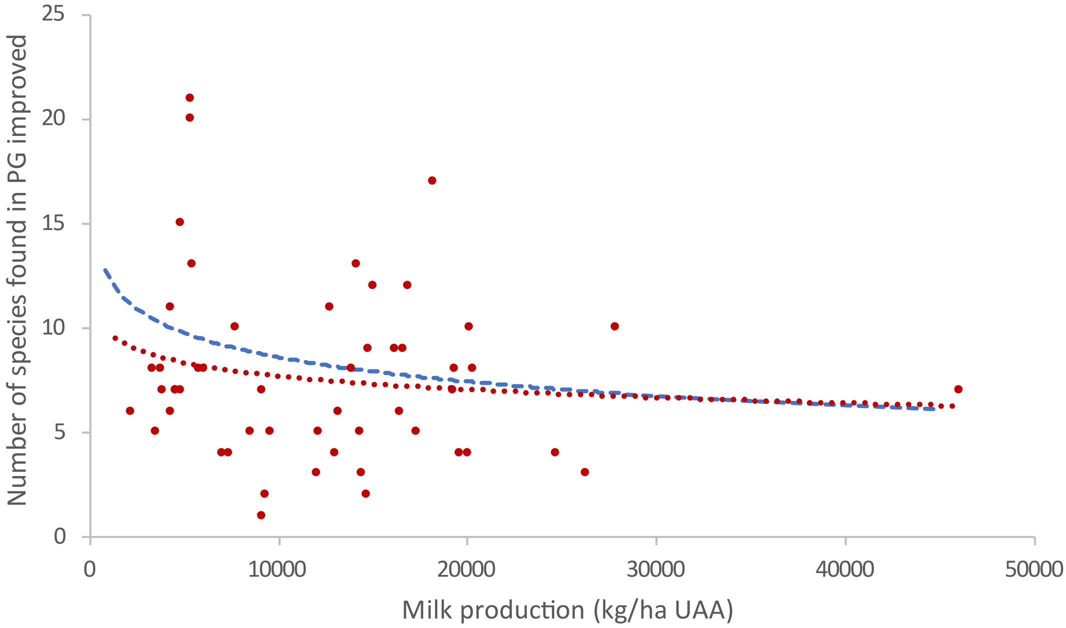

Figure 31. The number of plant species on improved PG as function of milk production per ha. The red dots are data points from the survey. The red dotted line results from a linear regression applied directly to the data and the blue dotted line was calculated by using the manufactured N fertilizer rate on improved PG from Fig. 33 in combination with eqn. 12.

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Climate change

The stocking rate of ruminants (in LU) can be calculated by multiplying the stocking rate of milking cows (Fig. 25) by the average ratio of total ruminants (in LU) relative to milking cows, i.e. 1.437, as mentioned in section 3.2. Up to a rent charge of *c*. 1,000 euro/ha, the calculated results are similar to the direct correlation in Fig. 32. The above-mentioned ratio of total ruminants relative to milking cows is only a little higher than the value of 1.383 used in Lombardi and Ravetto Enri (2021), possibly due to additional non-dairy animals in the specialised dairy farms of the 2019 survey, which were not taken into account in the farm typology rules.

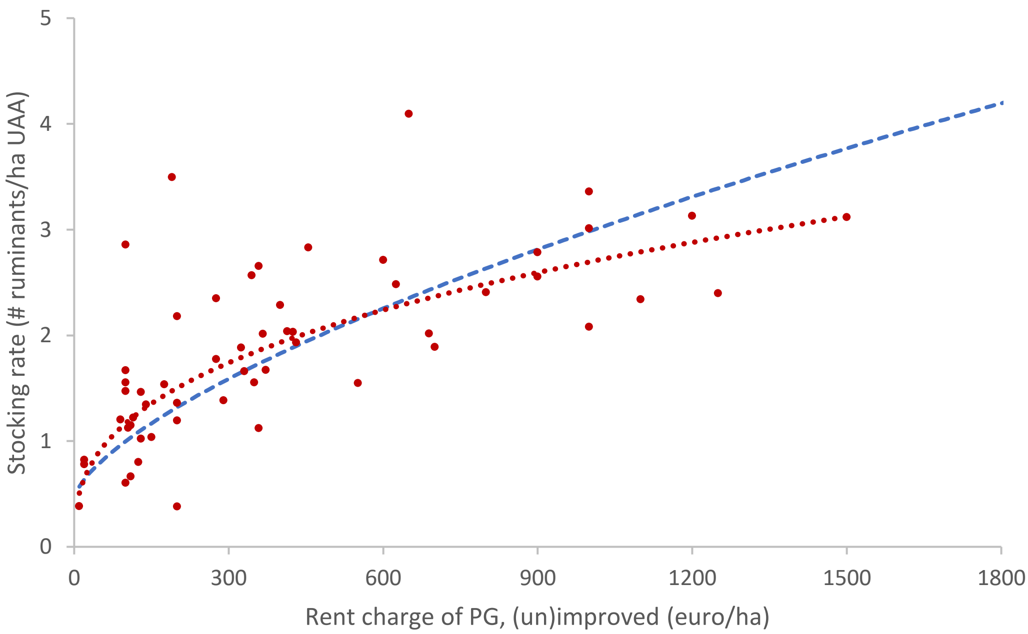

Figure 32. Stocking rate of total ruminants (in LU) as a function of PG rent charge. Red dots are data points from the survey. The red dotted line results from a linear regression applied directly to the data and the blue dotted line was calculated by multiplying the calculated stocking rate of milking cows (Fig. 20) by the average fraction of 1.437 (see section 3.1).

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The second indicator for the climate regulation ESS, determined as an outcome of the model, is the manufactured N fertiliser rate, which is calculated as a function of the milk production from Fig. 27 and the eqn. 6 and 18a (which refers to an adjusted N input per ha total PG). In Fig. 33, the calculated (dotted blue) line is similar to the direct correlation (red dotted) line from x = 10,000 onwards, but with considerable scatter, which was also visible in Fig. 14.

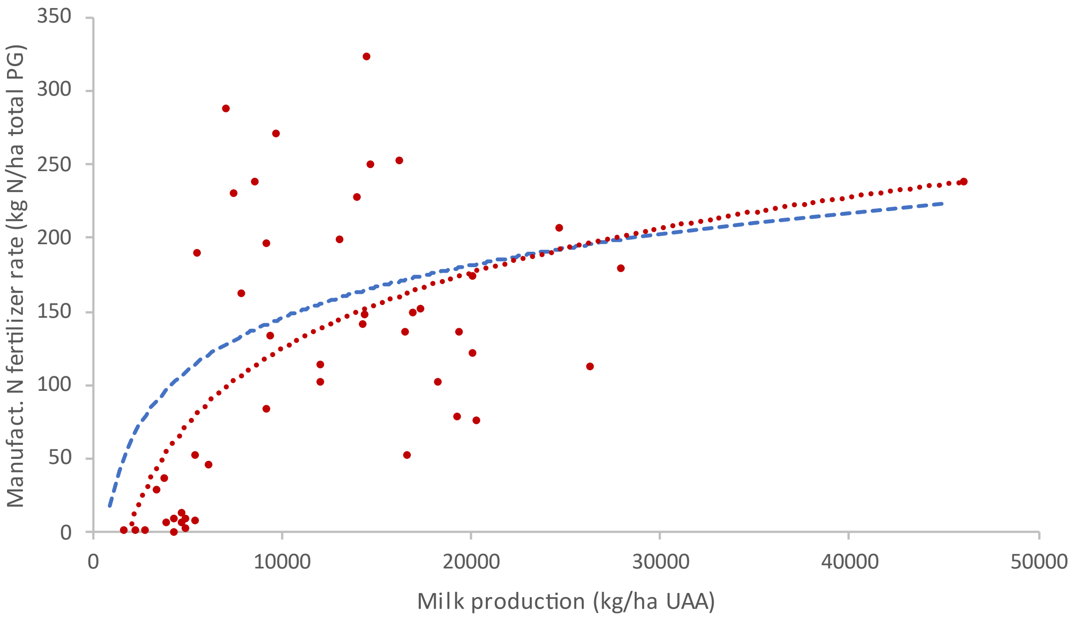

Figure 33. Manufactured N fertiliser rate on total PG as a function of milk production per ha. The red dots are data points from the survey. The red dotted line results from a linear regression applied directly to the data and the blue dotted line was calculated by applying eqn. 6 and 18a in combination with the calculated milk production per ha from Fig. 27.

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A second relation between manufactured N fertiliser rate and milk production per ha only takes the fertiliser use on improved PG into account and excludes any unimproved PG on each farm. In this case, both the direct regression (red dotted) line and the calculated (blue dotted) line show a very similar correlation with milk production intensity per ha. The calculated manufactured fertiliser N rate on PG improved can be used in the calculation of plant species diversity on PG improved (see section on 'Biodiversity and pollination', above).

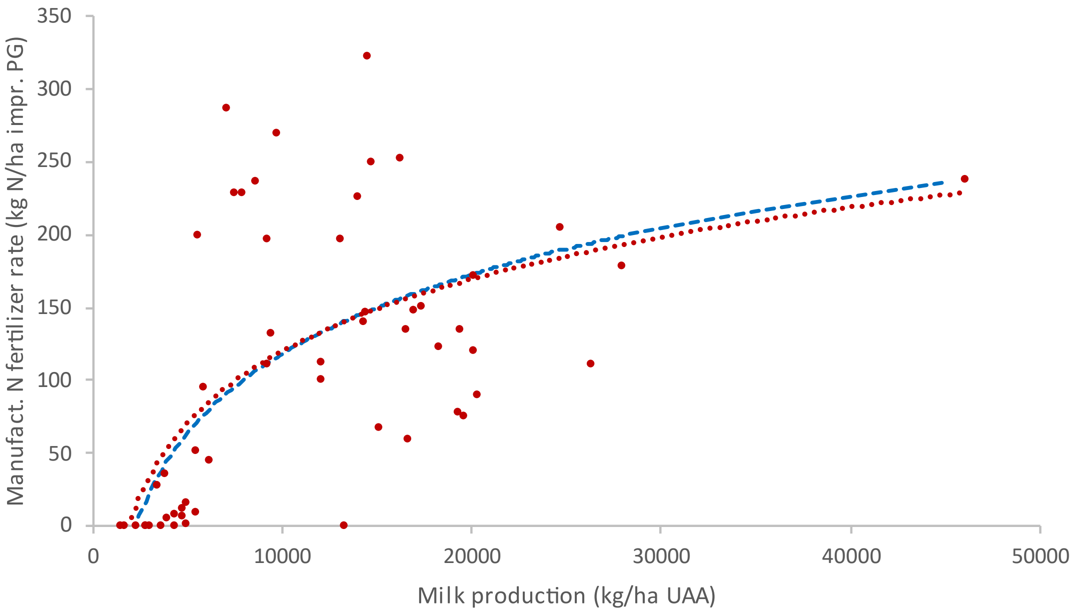

Figure 33a. Manufactured N fertiliser rate on improved PG as a function of milk production per ha. The red dots are data points from the survey. The red dotted line results from a linear regression applied directly to the data and the blue dotted line was calculated by applying eqn. 6 and 11 in combination with the calculated milk production per ha from Fig. 27.

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6. Discussion and conclusions

The correlations described in this report are not surprising, but seem to follow a certain logic, combining economic considerations with limitations due to natural constraints in PG grass productivity (per ha) and milk productivity (per cow). Higher costs need higher revenues and therefore higher income from milk in specialised dairy farms with >75% dairy LU (Fig. 5). Higher milk income directly links with higher milk production (Fig. 6), while this milk production can be obtained both via higher stocking rates of milking cows and higher milk production per cow (Fig. 7 and 8). The latter is limited (maximum annual productivity *c*. 10,000 kg milk per cow), thus the correlation with stocking rate is linear (Fig. 7), whereas the correlation with productivity per cow is curvilinear (Fig. 8). Producing milk requires feed and the two investigated sources for the selected specialised dairy farms (with >50% PG area) were imported (purchased) feed and grass from PG. So, milk production is positively correlated with imported feed and PG produced grass (Fig. 9, 10 and 11 at the per ha level; and Fig. 18, 19 and 20 at farm level). More grass from PG generally needs greater nitrogen supply to produce the grass, which partly translates into higher manufactured N fertiliser rates (Fig. 12, 13 and 15 per ha; Fig. 24 at farm level). Finally, higher N fertiliser rates generally correspond with fewer plant species in the sward and thus correlate with lower plant species diversity (Fig. 16). However, the analysis also shows how different aspects of the farm business are correlated. A farmer can buy feed or produce feed (grass and forage crops grown on farm), and these are in part exchangeable (Fig. 20 and related Fig. 21). Buying (more) feed and relying less on farm-produced feed may require less manufactured N fertiliser input to the farm, which may 'allow' greater plant species diversity on the PG of the farm (Fig. 16). However, this combination of higher feed purchase and lower fertilizer application is not likely according to the correlations (Fig. 18 and 19) and purchasing more feed seems not the best option for supporting biodiversity at a national or global scale (Chaudhary & Kastner, 2016; Jaureguiberry *et al*., 2022). However, overall impacts depend on the consequences of the purchased feed in the location where it was

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produced (Chaudhary & Kastner, 2016). Such external impacts of purchased livestock feed need to be included for a comprehensive analysis, but this was outside the scope of the survey and thus, the analysis of this report.

In addition, Fig. 22 illustrates an interesting correlation: farms with a higher milk production intensity per ha used more imported feed relative to their PG grass production. This can be understood by the same 'logic' already described above: more milk requires more feed and that has to be supplied by relatively more purchased feed because the grass production from PG is limited, either by natural, e.g. climatic, constraints and/or due to limitations from environmental legislation.

The synthesis model described in section 5 was built from the equations representing most of the correlations in sections 4.1 – 4.8 and only uses '*typical rent charge of PG in the area*' as an external input variable. This means that this rent charge acts as a driving variable in the model calculations that determines the outcomes, such as milk production intensity per ha, amount of purchased feed per ha, PG productivity and PG plant species diversity. By selecting eqn. 15a and 18a instead of eqn. 15 and 18, model results per ha were the same for different farm sizes (expressed in UAA). By additionally supplying a farm size (in UAA), variables can be calculated at farm level, such as total milk production per farm or manufactured N fertilizer input on PG. The model describes the response of variables and their mutual correlations, because all variables, except the rent charge, are connected in the model where the outputs of one equation were used as input for another. It may thus offer a better understanding of a number of dependencies that affect PG management and related ecosystem services in specialised European dairy farms. As illustrated in many figures of section 5, the model reproduces similar results compared to the results from direct regressions using the data points.

The importance of PG rent charge for the model results does not mean that other economic aspects of the farm business should be neglected, because in principle they could affect the 'starting' correlation in Fig. 5 between milk income and rent charge.

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To provide more 'space' for ESS other than food production, either the costs need to decrease or additional revenues, besides the income from selling milk, should be found. Those could come from selling a product made from milk with a higher margin, by diversification of the farm business, e.g. via additional income from tourism, or by payments for specific ESS other than food production. However, this study did not find other (economic) variables in the dataset that could improve the correlations, starting with the one in Fig. 5 (milk income versus rent charge).

Correlations of two efficiency indicators with milk production per ha were examined in this study, i.e. forage efficiency (Fig. 29) and fertiliser efficiency (Fig. 30). Generally, farms with higher milk production intensities per ha also had higher forage efficiencies, thus using less feed, imported and PG grass, per kg milk. This could be related to a number of causes, such as the nutritive value of the feed (higher quality in farms with higher milk production levels) or the genetic variety of the milking cow (higher feed conversion by milking cows in farms with higher milk production levels) , although these could not be analysed using the survey data. However, greater forage efficiency does not necessarily result in greater sustainability or lower environmental impact, as indicated by Jevons paradox (Polimeni et al., 2009), which suggests that if milk production is unconstrained the opposite may be true. In the case of manufactured N fertiliser efficiency, a number of low productivity farms had very high efficiency values, related to relatively (very) low manufactured N fertiliser application rates. This indicates a situation where other N sources are important, such as high clover cover in the PG sward and the efficient use of organic manures, but this was not further analysed. Low manufactured N fertiliser use for producing milk has environmental advantages (e.g. lower GHG emissions and higher plant species diversity), but if correlated with low productivity levels, it also has the disadvantage of using more land per kg milk (i.e. the inverse of milk production per ha). This illustrates a trade-off between delivering multifunctionality from grasslands (Schils et al., 2022) and meeting the demand for meat and milk along with the environmental costs or externalities associated with this. For a

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comprehensive analysis of food (specifically meat and milk) production versus environmental impact (or multifunctionality), total land use should be taken into account, which includes the land that was used for the production of purchased feed. Again, this was outside the scope of this study. Strikingly, for milk production levels of more than *c*. 5,500 kg milk per ha, no clear relation of manufactured N fertilizer efficiency with milk production per ha was found. This is related to the positive correlation between milk productivity and the ratio of imported feed to grass from PG (Fig. 22), because more imported feed means more manure at the farm that can be used as organic fertiliser in combination with the manufactured N fertiliser. An alternative cause could be the environmental conditions, where farms with higher milk productivities per ha are located in areas that allow higher N fertiliser rates combined with higher N uptake efficiencies, due to a more favourable climate and/or soil type.

The analysis of this study has a number of uncertainties. Firstly, there may be errors in the responses to the survey that were undetected. Secondly, for some correlations more or better data could be helpful, such as the total cost of production in Fig. 5, or the quality of feed sources in Fig. 22. Thirdly, data were significantly scattered in a number of correlations, e.g. Fig. 5, 12 and 16. This scatter is still unexplained by the regressions and illustrates the diversity of farms across Europe. The analysis in this study looks for average trends by applying regression as a tool to correlate variables and does not focus on explaining farms that deviate from the average line. However, much can also be learned from understanding the differences between these farms (especially the outliers) Explaining why these farms deviate can help to better understand how farms (can) manage their PG and deliver ESS. This additional research, focusing on specific farms, could be a topic for further investigation. Other aspects that need further research are a.o. (1) the role of manure in the farm (produced as a function of milk production, on-farm applied, imported or exported), (2) possible correlations with harvesting methods (grazing and/or cutting) and (3) the economic contribution of the arable part of UAA (selling arable products or used for feed production), next to (4) analysing the correlations for other farm types with PG, such as beef farms and

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sheep/goat farms. Studying other farm types could determine whether differences in PG management exist depending on the dominant type of livestock on the farm.

The farms in the survey were selected from existing farm networks in 12 countries covering a large part of the biogeographical conditions in Europe. However, it has not been verified whether these farms are representative of all farms in Europe. The correlations in this report may therefore be biased and not fully applicable to other dairy farms in Europe. However, the logic as explained above, makes it plausible that the direction and the form of the correlations may also be relevant for other dairy farms.

In principle, the correlations are spatial, i.e. explaining part of the variation among farms at different locations in Europe, and may not necessarily represent causal relations between variables. Causal relations are necessary to predict how farms will change e.g. if their production costs decline or their revenues increase, which cannot thus be concluded from this report. On the other hand, the model can be used to gain more insight into the general nature of the interlinkages between external drivers, farm structure, PG management and some related ESS on specialised dairy farms in Europe.

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Annex 1 Livestock Units (LU)

Table 1. Values for LU per livestock species and age category.

Livestock species	Age category	LU value
Beef (Rearing and Finishing) animals	Beef 0-1	0.4
	Beef 1-2	0.7
	Beef 2+	0.9
Suckler Beef (for breeding) animals	Suckler cows	0.8
	Suckler beef 0-1	0.4
	Suckler beef 1-2	0.7
	Suckler beef 2+	0.9
	Bulls sold for meat	1
	Breeding bulls	1
Sheep for meat	Ewes	0.1
	Lambs	0.04
	Breeding rams	0.1
Sheep for milk	Ewes	0.1
	Lambs	0.04
	Breeding rams	0.1
Dairy animals	Cows	1
	Youngstock	0.55
	Breeding bulls	1
Goats for meat		0.1
Goats for milk		0.1
Pigs -Intensive Breeding		0.5
Pigs -Free Range		0.5
Deer		0.4
Poultry for meat		0.007
Poultry for eggs		0.014
Horses		0.8

Note: above list of LU values has been defined for its use in the SUPER-*G* project and is based on information supplied by Eurostat. Missing values in Eurostat data have been estimated.

Source:

https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock_unit_(LSU)

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Annex 2 Milk selling price

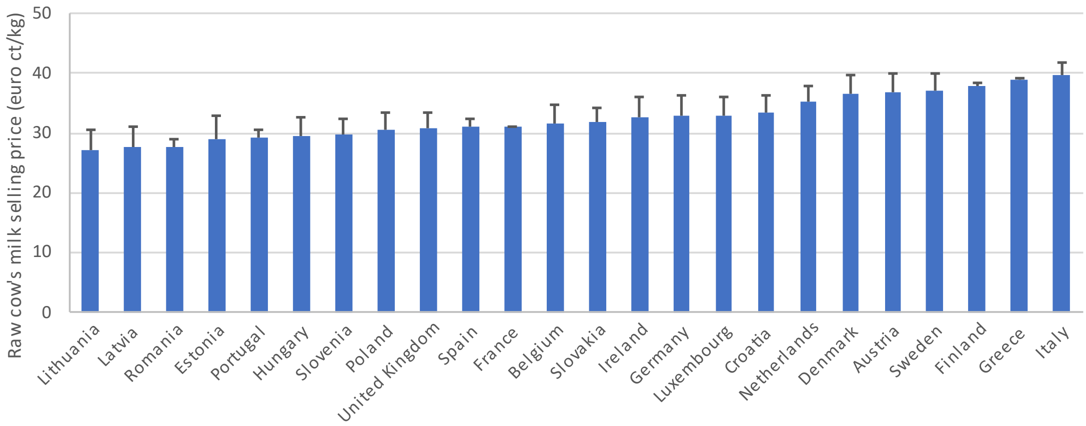

Figure 1. Raw cow's milk selling price in European countries. Bars represent the average values of the period 2016 – 2020 and the lines illustrate the standard deviation in the same period per country.

Source: Eurostat's '*Selling prices of animal products (absolute prices) - annual price (from 2000 onwards) [APRI_AP_ANOUTA__custom_1266172]*'

Date extracted: 06 Sept. 2021

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