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Sustainability Effects of the Uptake of More Grass-Based Feeding Practices: Evidence From Sweden

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ABSTRACT

We examine the effects of the uptake of grass-based feeding practices on the economic, environmental, and social dimensions of farm sustainability. More specifically, we analyse the predictive effects of an increase in grassland or ley area on farm net income, total working hours, and fertiliser expenditure. Our analysis utilises farm-level data from Swedish dairy farms spanning the period 2002–2021. Drawing on a directed acyclic graph (DAG), we assess both the average and distributional effects using panel regression with fixed effects and penalised panel quantile regression methods, respectively. Our results show that an increase in either grassland or ley area is associated with a decrease in both farm net income and fertiliser expenditure, alongside an increase in total working hours on average. Our distributional analysis further indicates that these effects vary across the quantile distribution of the outcome variables. Finally, the results show that an increase in either grassland or ley area leads to a reduction in milk yield, feed cost and the cost of veterinary services. Overall, our findings highlight the trade-offs associated with farmers' transition towards the uptake of more grass-based feeding practices and the policy implications.

1 | Introduction

Dairy production in the European Union (EU), including Sweden, involves the use of high amounts of concentrate feeds (Balaine et al. 2023; Krizsan et al. 2021; Mack and Kohler 2019; Swensson et al. 2017). This is associated with environmental footprints from feed production, import, and processing (Krizsan et al. 2021). The uptake of more grass-based feeding systems where dairy cows are fed with a high amount of grasses and a relatively lower amount of concentrates compared to current feeding regimens has been identified as a promising way to enhance dairy farm sustainability (Balaine et al. 2023; Karlsson et al. 2020). A grass-based feeding system can, from a sustainability perspective, (i) improve animal welfare, (ii) enhance ecosystem services and grassland biodiversity, (iii) decrease the environmental footprints related to feed production, and (iv) reduce the feed-food competition between animals and humans (Lindberg et al. 2021; Tarekegn et al. 2021).

Nevertheless, the uptake of more grass-based feeding practices in Europe, including Sweden is low (Karlsson et al. 2020; Patel et al. 2017). Few European countries in recent times have put in place policies to encourage the uptake of grass-based feeding practices in dairy farms. For example, the Swiss government in 2014 introduced a voluntary grass-based milk and meat programme, combined with economic incentives to restrict the amount of concentrate feed and increase the use of grass feed among dairy farmers (Mack and Kohler 2019). While the Irish government between 2010–2012 and 2017–2019 also supported and encouraged farmers' uptake of grass-based feeding practices through an extension program (Balaine et al. 2023). To this date, there are limited

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empirical studies on the sustainability impacts of the uptake of grass-based feeding practices with few exceptions, including Balaine et al. (2023), Le Gloux et al. (2023) and Mack and Kohler (2019). More importantly, to the best of our knowledge, there is no empirical study in a Northern European context, although the conditions for natural grassland and ley cultivation are often favourable in those areas.

In this paper, we examine the sustainability effects of the uptake of more grass-based feeding practices by dairy farmers in Sweden. Specifically, we examine the predictive effects of grassland or ley area increase on indicators of farm sustainability. We employ an unbalanced panel dataset of Swedish dairy farms obtained from the EU Farm Accountancy Data Network (FADN), spanning a 19-year time period from 2002 to 2021. We anchor our analysis on a directed acyclic graph (DAG) for our model estimation (Hünermund and Bareinboim 2019; Pearl 2009; Pearl and Mackenzie 2018; Heckman and Pinto 2022, 2024).

Guided by the DAG, we adopt panel regression with fixed effects and penalised panel quantile regression with fixed effects to examine the average and distributional effects of grassland or ley area increase on farm net income, total working hours, and fertiliser expenditure. We also examine the potential mechanisms that drive the main results and triangulate the baseline results using other econometric approaches underpinned with different assumptions. Overall, our main results indicate that an increase in either grassland or ley area is associated with a decrease in farm net income and fertiliser expenditure, along with an increase in total working hours. The findings also suggest that these effects vary across the quantile distribution of the outcome variables. Moreover, the results indicate that the increase in total working hours is primarily driven by a rise in family working hours. Finally, the findings show that an increase in grassland or ley area is associated with a decrease in milk yield, the cost of purchased feed and the cost of veterinary services.

This study contributes to the literature in three main ways. First, the study provides novel insights into the sustainability impacts of the uptake of grass-based feeding practices. In particular, previous studies that have examined the effects of the uptake of grass-based feeding practices have mainly focused on the economic and environmental aspects of sustainability (Balaine et al. 2023; Mack and Kohler 2019) with limited information on the social dimension. Hence, besides evaluating the economic and environmental aspects of sustainability, the current study also examines the social implications associated with the uptake of grass-based feeding practices. This allows for a more nuanced understanding of the farm-level sustainability effects of the uptake of more grass-based feeding to better inform policy.

Second, earlier studies that have evaluated the sustainability impacts of the uptake of grass-based feeding practices have often examined the average effects using either a Two-Way Fixed Effects method (Balaine et al. 2023), Difference-in-Differences combined with an Agent Based simulation modelling approach (Mack and Kohler 2019) or variable cost functions (Le Gloux et al. 2023). However, several studies have shown that average effects often mask the distributional effects (Abrevaya and Dahl 2008; Chernozhukov and Hansen 2006; Roger et al. 2017). Thus, we examine the distributional effects in addition to the average effects. This helps to examine the full effects as well as identify which subgroup of farms will benefit from the uptake of grass-based feeding practices.

Finally, we contribute to expanding the number of studies that have empirically examined the sustainability impacts of the uptake of grass-based feeding practices in Europe. Mack and Kohler (2019) investigated the sustainability effects of Swiss farmers' adoption of grassland-based milk and meat production. Le Gloux et al. (2023) explored the effects of increasing grassland area on the marginal costs of milk production and associated payment for environmental services in France. Balaine et al. (2023) studied farmers' extension participation and the corresponding effects on the uptake of grass-based feeding practices in Ireland. To the best of our knowledge, the number of studies in a Northern European context is limited and thus the current study contributes to filling this gap by examining the predictive effects of grassland or ley area increase on farm net income, total working hours and fertiliser expenditure. This is important since the agro-climatic conditions, which affect agricultural production practices, in Northern Europe are different from other parts of Europe. Similarly, the institutional and market conditions are not necessarily the same, and thus the results associated with farmers' uptake of more grass-based feeding practices are likely to be different. This is vital for designing policies to encourage farmers' uptake of grass-based feeding practices.

The set up of the paper is as follows: Section 2 presents the data and the variables used. Section 3 describes the DAG and estimation approach; while Section 4 presents the results. Section 5 presents the discussion and conclusion.

2 | Data

The study uses data from the Swedish Farm Accountancy Data Network (FADN) provided by the Swedish Board of Agriculture. The FADN data is a comprehensive and standardised survey-based data set for all EU member states, and is purposely used for research to support policy decision making. An unbalanced panel dataset that covers the period 2002 to 2021 was compiled after farms with missing key variables of interest were removed. The final sample contains 902 individual dairy farms, resulting in 4668 farm observations over the 19-year panel period. For the purpose of this study, we used farm-level information on production specialisations (e.g., milk only, milk and fattening, and milk and crop specialisations), the expenditure on purchased concentrate, culling rate, stock density, age of the farm manager, and the amount of Common Agricultural Policy (CAP) support received by a farm as control variables; our key variables of interest are the area of grassland and area of ley.

For the outcome variables, we proxy economic, social and environmental aspects of sustainability with farm net income, total working hours and fertiliser expenditure, respectively. The farm net income is calculated as the farm net value added minus wages, rent and interest paid plus subsidies and taxes on investment. We hypothesise that an increase in either grassland or ley area should increase the total cost of production and thus the farm net income (Mack and Kohler 2019; Balaine et al. 2023).

Most studies (e.g., Kleinhanss and Ehrmann 2008; Hennessy et al. 2013; Balaine et al. 2023) categorise social indicators into four main areas: human capital and education, working conditions, quality of life, and livelihood security. For example, the education level of farm households has been used as an indicator in farm succession studies, while workload has been assessed in terms of work-life balance (Hennessy et al. 2013; Balaine et al. 2023). Following Hennessy et al. (2013) and Balaine et al. (2024), we use total working hours as a proxy for social sustainability. We anticipate that an increase in either grassland or ley area would lead to higher total production working hours in the field, as farmers would require more time to manage the additional grassland or ley. Conversely, an increase in grassland or ley area may also raise the demand for labour, which, in turn, could increase the total cost of production. However, a rise in labour costs may force farmers to reallocate more time from social activities or leisure to farm work.

Finally, we use the total expenditure on purchased synthetic fertiliser as a proxy for fertiliser use. This is based on the reasoning that increasing grass-based feeding practices can help reduce fertiliser use as grasses such as clovers fix atmospheric nitrogen (N) into the soil (Jørgensen et al. 1999; Ledgard et al. 2001; Høgh-Jensen and Schjoerring 1997; Hatch et al. 2007), thereby making available N to grasslands, which is required for animal feed (Johnson and Thomson 1996; Fraser et al. 2004; Peyraud et al. 2009). Moreover, grasses require a limited amount of fertiliser compared to grain production for feeds. We envisage that an increase in either grassland or ley area would decrease fertiliser expenditure and thus the demand for synthetic fertilisers.

2.1 | Descriptive Statistics

Table 1 presents summary statistics and the explanation of the variables used. The average stock density, farm size, and culling rate are about 1.1 livestock unit/ha (LU/Ha)[1], 104 ha, and

TABLE 1 | Summary statistics and definitions of variables used.

Variable	Explanation	Median	Mean	SD
Dependent variable				
Grassland area	Area of grassland per livestock unit (Ha/LU)	0.942	1.105	1.708
Ley area	Area of ley (Ha/LU)	0.696	0.815	1.155
Control variable				
Stock density	Density of ruminant grazing livestock (LU/Ha)	1.045	1.143	0.579
Total farm size	Total farm size in hectare (ha)	71.350	103.987	100.653
Specialise in milk and fattening	Proportion of farms specialised in milk and fattening production	0.000	0.026	0.158
Specialise in milk	Proportion of farms specialised in milk production	1.000	0.956	0.204
Specialise in milk and crop	Proportion of farms specialised in milk and crop production	0.000	0.015	0.120
CAP support	Amount of CAP support received in Swedish Krona (SEK)	11,156.840	189,655.400	264,351.900
Culling rate	Cows removed or sold due to low milk production or ill health or death as a percentage of the total number of animals	0.150	0.196	0.275
Amount of concentrate used	Total expenditure on purchased concentrate (SEK/LU)	4109.588	4204.654	2291.742
Age	Age of the farmer in years	53.570	53.575	9.477
Outcome variable				
Farm net income	Farm net value added minus wages, rent and interest paid plus subsidies and taxes on investment (SEK/LU)	3837.731	3904.628	9102.961
Total working hours	Time worked in hours by total labour input on holding (h/LU)	68.102	85.478	83.797
Amount of fertiliser used	Total expenditure on purchased synthetic fertiliser (SEK/Ha)	472.312	558.764	543.154

Note: SD denotes standard deviation.

0.2, respectively. About 96% of the farmers specialised in only milk production, and the average age of a farm manager is about 54 years. The average amount of CAP support received by a farmer is about 190,000 SEK. Also, the average farm net income, total working hours, and fertiliser expenditure are about 3900 SEK/LU, 85 h/LU, and 559 SEK/Ha, respectively. Finally, the average grassland area and ley area are around 1.1 and 0.815 Ha/LU, respectively.

Furthermore, we follow Cattaneo et al. (2019) and adopt the binscatter plot to examine the relationship between our main outcome variables (i.e., farm net income, total working hours, fertiliser expenditure) and grassland and ley area, respectively.[2] We account for all the control variables presented in Table 1, including year fixed effects in estimating the binscatter regression.

Figure 1 presents the relationship between the outcome variables and grassland (top panel) and ley area (bottom panel). The figure shows that an increase in either grassland or ley area is negatively associated with a decrease in both farm net income and fertiliser expenditure. On the other hand, the figure reveals that an increase in grassland or ley area is associated with an increase in total working hours on dairy farms. However, it is important to note that these results are suggestive, as the observed patterns could be influenced by several unobserved factors. To address this, we employ a panel data regression analysis with fixed effects to account for potential unobserved factors in the estimation.

3 | Effects of the Uptake of Grass-Based Feeding Practices

We motivate our estimation using the directed acyclic graph (DAG) (Hünermund and Bareinboim 2019; Pearl 2009; Pearl and Mackenzie 2018) in Figure 2. The DAG helps to identify the pathways via which a treatment or a variable affects an outcome. It also helps to identify which variables need to be

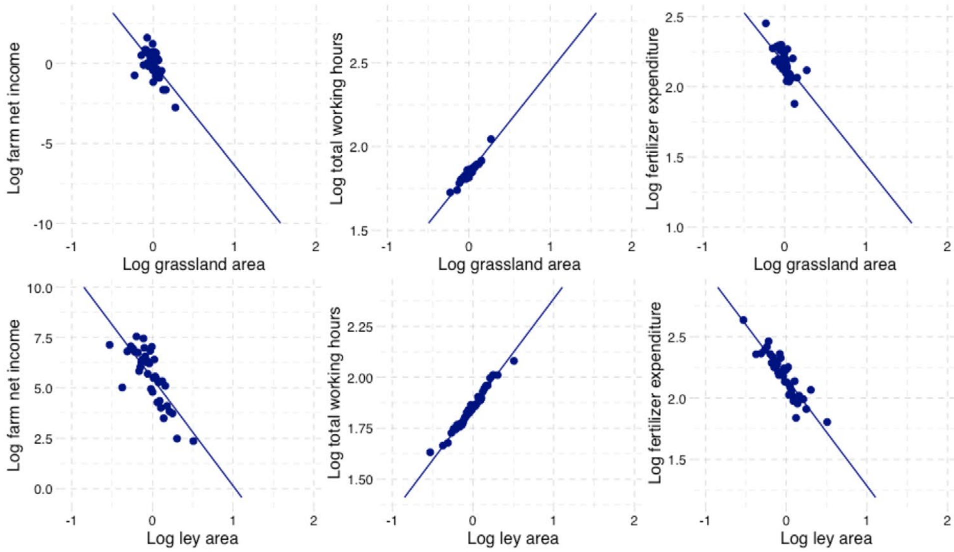

FIGURE 1 | The figure shows binned scatter plots of the outcome variables (Log farm net income, Log total working hours and Log fertiliser expenditure) against Log grassland area (top panel) and Log ley area (bottom panel). We account for the control variables as in Table 1. The local regression line was estimated following the proposed recommendation of Cattaneo et al. (2019). [Colour figure can be viewed at wileyonlinelibrary.com]

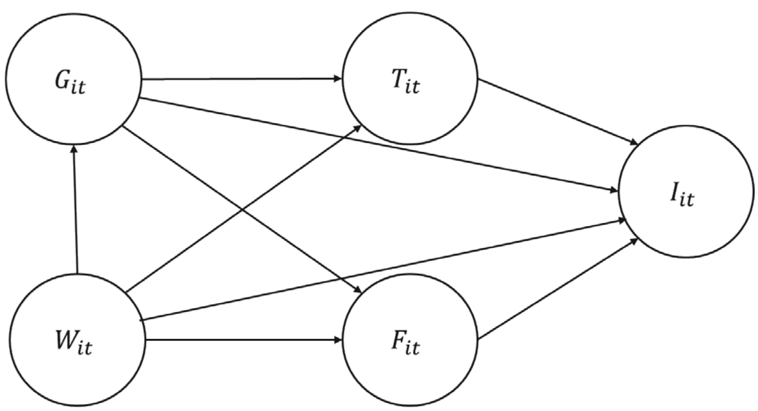

FIGURE 2 | The directed acyclic graph underpinning our estimation. W_{it} denotes the control variable as reported in Table 1. Note that W_{it} vary across farms and time and affect all the other outcome variables (i.e., T_{it}, F_{it} and I_{it}). T_{it}, F_{it} and Y_{it} denote total working hours, fertiliser expenditure and farm net income, respectively.

conditioned on in order to avoid biased estimates (Pearl 2009; Pearl and Mackenzie 2018). Specifically, the arrows in Figure 2 indicate the pathways via which the uptake of grass-based feeding practices can affect economic, environmental and social aspects of farm sustainability. In other words, it describes how grassland or ley area G_{it}, control variable W_{it}, total working hours T_{it}, fertiliser expenditure F_{it}, and farm net income I_{it} interacts together.

For example, changes in government policies (e.g., direct farm support) may induce farmers to increase their animals' grass feed intake, thereby potentially causing farmers to increase their forage areas (i.e., grassland area or ley area G_{it}) (Nordin and Manevska-Tasevska 2013). This can directly impact farm net income I_{it}, total working hours T_{it} and fertiliser expenditure F_{it}. Conversely, both farmers' socio-economic and farm characteristics (e.g., farm size, production orientation, etc.) W_{it} can influence farmers' decision to increase their animals' grass feed intake and consequently affect the expansion of forage areas (i.e., grassland area or ley area GR_{it}). This, in turn, can indirectly affect farm net income I_{it}, total working hours T_{it} and fertiliser expenditure F_{it}.

Generally, our analysis aims at uncovering the predictive effects of grassland area or ley area increase on farm net income, total working hours, and fertiliser expenditure, controlling linearly for the control variables in Table 1 and other unobserved factors through farm and year fixed effects. In summary, our analysis may be viewed as premised on the unconfoundedness assumption.

We motivate our model estimation based on the pathways:

Farm net income	$G_{it} \leftarrow W_{it} \rightarrow I_{it}$	[GW → I]
Total working hours	$G_{it} \leftarrow W_{it} \rightarrow T_{it}$	[GW → T]
Fertiliser expenditure	$G_{it} \leftarrow W_{it} \rightarrow F_{it}$	[GW → F]

3.1 | Identification and Parameter Estimation

The quantitative model for the pathway is given by the following econometric structural outcome model:

$$y_{it} = \alpha G_{it} + \gamma W_{it} + \varepsilon_{it} \qquad \varepsilon_{it} \perp G_{it}, W_{it} \qquad [\text{GW} \rightarrow \text{Y}]$$

where α denotes potential values of either grass or ley area, γ represents the potential values of observed and unobserved components (i.e., farm and year fixed effects) of the farm characteristics W_{it}, and ε_{it} denotes the stochastic shock and it is assumed to be orthogonal to the explanatory variables G_{it}, and W_{it}.

The pathway can be estimated using the panel regression approach:

$$y_{it} = \alpha G_{it} + \nu W_{it} + \delta_i + \gamma_t + \varepsilon_{it} \tag{1}$$

where y_{it} is the outcome variable (i.e., I_{it}, T_{it} and F_{it}) of farm i in time t, G_{it} is the grassland area or ley area, α captures the effect of increases in either grassland or ley area, ν denotes the coefficients of the observed control variables, W_{it} is a set of variables to control for time-varying farm-level factors (e.g., stock density, culling rate, farm size, production orientation, age of the farmer etc.), δ_i captures farm-specific effects that control for any time-invariant farm-specific characteristics, γ_t captures time-specific effects that control for national aggregate trends, and ε_{it} denotes the standard error.

For the parameters identification, we assume the error in Equation (1) is orthogonal to the control variables, including the farm and year fixed effects. We also assume that the variables related to an increase in grass-based area (i.e., grassland area and ley area) can be reasonably considered as good as randomly assigned after conditioning on the control variables, including farm and year fixed effects (Hünermund and Bareinboim 2019; Pearl 2009; Pearl and Mackenzie 2018).

3.2 | Estimating the Average Effects

One can estimate Equation (1) using the within fixed effects (FE) or FE regression estimator. The within FE estimator filters out time-invariant unobserved variables at the farm and year levels that can influence farmers uptake of grass-based feeding practices. However, the FE estimator assumes homogeneous effect and thus can be biased if the effect is heterogeneous across time and individual farms (De Chaisemartin and D'Haultfoeuille 2023; Roth et al. 2023). As such, we follow Pesaran (2006) and Bai (2009) and adopt the Interactive Fixed Effects (IFE) method that accounts for unobserved heterogeneity across both farm and year in the estimation. Specifically, we adopt the IFE approach proposed by Bai (2009) that allows for heterogeneity in the slope coefficients:

$$y_{it} = \alpha G_{it} + \nu W_{it} + f_t' \lambda_i + \varepsilon_{it} \tag{2}$$

where f_t' denotes a vector of unobservable common factors, or latent time-varying factors, and λ_i represents factor loadings (i.e., determines to what extent an individual farm is affected by f_t'). We note that G_{it} and W_{it} may be correlated with the common factors, factor loadings, or both. In such cases, ignoring the factor structure leads to inconsistent estimates of the regression coefficients (Bai 2009; Pesaran 2006). In summary, the IFE estimator accounts for heterogeneity in estimating the slope coefficients (Bai 2009; Pesaran 2006).

3.3 | Estimating the Distributional Effects

The average effect often masks the distributional effects (Abrevaya and Dahl 2008; Koenker 2004). In this regard, we follow Koenker (2004) and examine the effects of an increase in either grassland or ley area on the outcome distribution. To this end, we estimate the panel quantile model as:

$$Q_{y_{it}}\left(\tau \mid g, \alpha_i\right) = \sigma_i + g_{it}\beta(\tau) \tag{3}$$

where y_{it} is the outcome variable (e.g., farm net income, total working hours, fertiliser expenditure) of farm i in year t, g_{it} are the observed variables W_{it}, including grassland area or ley area, σ_i is the individual effect and $\tau \in (0,1)$ is a quantile index. We estimate Equation (2) using the penalised estimation approach proposed by Koenker (2004). The estimator treats the individual effects as a pure location shift parameters common to all quantiles and subject to the ℓ_1 penalty (Koenker 2004). In other words, Koenker (2004) suggested the penalised estimator $\hat{\alpha}(\lambda), \hat{\beta}(\lambda,\tau)$:

$$\hat{\alpha}(\lambda), \hat{\beta}(\lambda,\tau), \ldots, \hat{\beta}(\lambda,\tau_q) := \arg\min \frac{1}{nT} \sum_{k=1}^{q} \sum_{i=1}^{n} \sum_{t=1}^{T} \vartheta_k \rho_\tau (y_{it} - \sigma_i - g\beta(\tau)) + \lambda \sum_{i=0}^{n} |\sigma_i| \quad (4)$$

where $\vartheta_1 \ldots \vartheta_q$ are the nonnegative weights, and $\lambda \geq 0$ is the penalty level. The estimation of Equation (3) relies on the tuning parameter λ. The penalised estimation approach controls for all individual unobserved heterogeneity (i.e., $\sigma_i \to 0$) in the estimation (Roger et al. 2017).

4 | Main Results

4.1 | Average Effects of Grassland or Ley Area Increase on Farm Net Income, Total Working Hours and Fertiliser Expenditure

We first examine the average effects of an increase in either grassland or ley area on farm net income, total working hours and fertiliser expenditure. Tables 2 and 3 present the estimates for grassland area and ley area, respectively. Model 1 assumes a homogeneous slope coefficient, while model 2 assumes a heterogeneous slope coefficient. Note that model 2 is our preferred model. Overall, the results (both models 1 and 2) suggest that the coefficient estimates are qualitatively similar. However, it is worth noting that model 2 (i.e., IFE estimator) does not suffer from omitted variable bias, allows for

TABLE 2 | Predictive effects of grassland area increase on farm net income, total working hours, and fertiliser expenditure.

	Log farm net income (GW → I)		Log total working hours (GW → T)		Log fertiliser expenditure (GW → F)	
Variable	**(1)**	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
Log grassland area	−6.3832*** (1.4445)	−5.3374*** (0.8694)	0.6097*** (0.0465)	0.5135*** (0.0204)	−0.7273*** (0.1745)	−0.5422*** (0.1194)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Farm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4668	4668	4668	4668	4668	4668
R^2	0.0206		0.6145		0.1263	

Note: Standard errors are in parentheses and clustered at the farm level. Model (1) assumes homogeneous effect, while model (2) assumes heterogeneous effect. Model 2 is our preferred model estimates. Model (1) is estimated using the conventional two-way fixed effects (TWF) method, while model (2) is estimated using the Interactive fixed effects (IFE) approach. Table A1 reports the full estimates.
*$p<0.1$.
**$p<0.05$.
***$p<0.01$.

TABLE 3 | Predictive effects of ley area increase on farm net income, total working hours, and fertiliser expenditure.

	Log farm net income (GW → I)		Log total working hours (GW → T)		Log fertiliser expenditure (GW → F)	
	(1)	**(2)**	**(1)**	**(2)**	**(1)**	**(2)**
Log ley area	−5.8103*** (1.6208)	−4.4381*** (1.0004)	0.2289*** (0.0174)	0.2242*** (0.0089)	−0.3643*** (0.0917)	−0.6119*** (0.1402)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Farm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4397	4397	4397	4397	4397	4397
R^2	0.0726		0.1092		0.0076	

Note: Standard errors are in parentheses and clustered at the farm level. Model (1) assumes homogeneous effect, while model (2) assumes heterogeneous effect. Model 2 is our preferred estimate. Model (1) is estimated using the conventional two-way fixed effects (TWF) method, while model (2) is estimated using the Interactive fixed effects (IFE) approach. Table A2 reports the full estimates.
*$p<0.1$.
**$p<0.05$.
***$p<0.01$.

cross-section dependence, and is robust in the presence of unobserved time-varying heterogeneity and dynamic treatment effects (Bai 2009).

Specifically, Table 2, model 2, indicates that a 1% increase in grassland area is associated with a decrease in farm net income and fertiliser expenditure by about 5% and 0.5%, respectively. By contrast, the result suggests that a 1% increase in grassland area is associated with an increase in total working hours by about 0.5%, on average. To anchor the magnitudes, the result suggests that an increase in grassland area by 110 m^2/LU or 0.011 Ha/LU (0.01×1.1) contributes to about 195 SEK/LU (0.05×3904 SEK/LU) reduction in farm net income, increases total working hours by 0.4 h/LU (0.005×85 h/LU), and reduces fertiliser expenditure by around 4 SEK/Ha (0.005×559 SEK/Ha).

Turning to Table 3, model 2, the result suggests that a 1% increase in ley area is associated with a decrease in farm net income and fertiliser expenditure used by around 4% and 0.6% respectively, on average. On the other hand, the finding shows that a 1% increase in ley area is associated with an increase in total working hours by about 0.2%. In terms of the magnitude of the estimate, the result suggests that an increase in ley area by about 100 m^2/LU or 0.01 Ha/LU leads to a reduction in farm net income by about 156 SEK/LU, increases total working hours by 0.17 h/LU, and reduces total expenditure on purchased synthetic fertiliser by about 3 SEK/Ha.

4.2 | Distributional Effects of Grassland or Ley Area Increase on Farm Net Income, Total Working Hours and Fertiliser Expenditure

Given that the average estimates in Tables 2 and 3 masked the distributional effects, we examine the distributional effects of an increase in either grassland or ley area on the outcome variables. Figures 3 and 4 plot the distributional effects estimates for both grassland area and ley area, respectively. Note that the shaded region denotes the 95% confidence intervals, and the point denotes the coefficient estimates.

Overall, Figures 3 and 4 suggest that the coefficient estimates are heterogeneous across the entire outcome distribution. Specifically, the figures show that the effect of an increase in either grassland area or ley area is negative at lower quantiles (i.e., below 0.5 quantiles) and positive at the upper quantiles for farm net income. The figures also indicate that the effect of an increase in either grassland area or ley area is positive and heterogeneous across the quantiles of the total working hours. On the other hand, the figures imply that the effect of an increase in either grassland area or ley area is heterogeneous across the quantiles of fertiliser expenditure, but more negative below the 0.5 quantiles.

In all, compared to the average estimates for the farm net income, the distributional estimates (Figures 3 and 4) imply that farmers at the upper quantile indices or above the 0.5 quantiles may benefit from the uptake of more grass-based feeding,

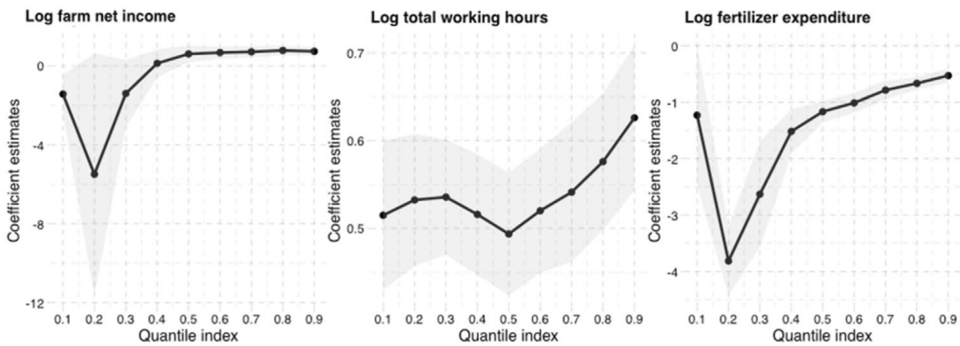

FIGURE 3 | Distributional effects of grassland area increase on Log farm net income (GW → I), Log total working hours (GW → T) and Log fertiliser expenditure (GW → F). The shaded region denotes the 95% confidence intervals. We accounted for all control variables as in Table 1 in the estimations.

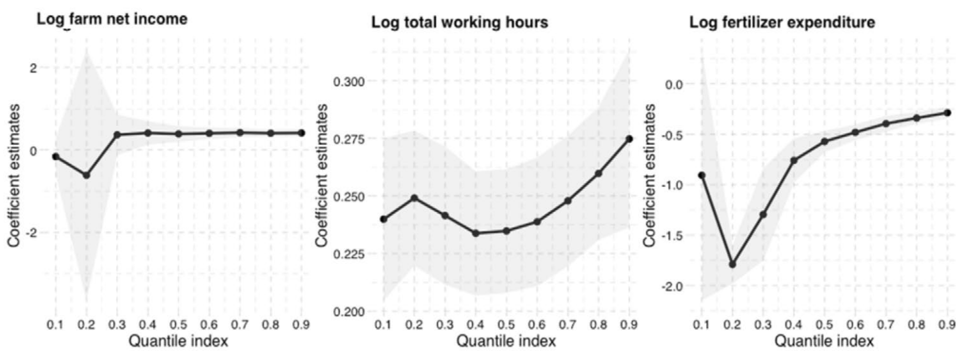

FIGURE 4 | Distributional effects of ley area increase on Log farm net income (GW → I), Log total working hours (GW → T) and Log fertiliser expenditure (GW → F). The shaded region denotes the 95% confidence intervals. We accounted for all control variables as in Table 1 in the estimations.

and that the average effects estimate for the farm net income is more closely aligned with the lower tail of the quantile distribution. This result suggests caution in the interpretation of the negative effects of the uptake of grass-based feeding practices on farm net income at the average level, as well as caution in drawing inferences without considering the distributional effects. The figures further reveal that the observed positive and negative effects of the uptake of grass-based feeding practices on total working hours and fertiliser expenditure, respectively, at the average level are in line with the distributional effect estimates.

4.3 | Decomposition of the Total Working Hours

We note that the total working hours in Tables 2 and 3 consist of both family and hired labour. Therefore, we further examine which of these sources primarily drives the main results presented in Tables 2 and 3, as well as Figures 3 and 4. Tables 4 and 5 present the decomposition of total working hours into family and hired labour in relation to grassland and ley, respectively. Both tables suggest that an increase in either grassland or ley area is associated with a greater increase in family labour hours compared to hired labour hours. This finding implies that the uptake of more grass-based feeding practices may shift family labour allocation from non-agricultural to agricultural activities.

4.4 | Mechanisms Underpinning the Effects of the Uptake of More Grass-Based Feeding Practices

We explore the potential mechanisms via which an increase in either grassland area or ley area may affect farm sustainability. To this end, we estimate the distributional effect of an increase in either grassland area or ley area on (i) milk yield (kg/cows), (ii) cost of brought-in or purchased feed (SEK/LU), and (iii) cost of veterinary services (SEK/LU). We acknowledge that other variables, apart from the ones we focus on, could also mediate these mechanisms.

TABLE 4 | Predictive effects of grassland area increase on total working hours for family and hired labour.

	Family labour (GW → T)		Hired labour (GW → T)	
	(1)	(2)	(1)	(2)
Log grassland area	0.5913*** (0.0469)	0.5567*** (0.0244)	0.1628 (0.1066)	0.0042 (0.0107)
Controls	Yes	Yes	Yes	Yes
Farm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	3197	3197	3197	3197
R^2	0.6158		0.0075	

Note: Standard errors are in parentheses and clustered at the farm level. Model (1) assumes homogeneous effect, while model (2) assumes heterogeneous effect. Model 2 is our preferred model estimates. Model (1) is estimated using the conventional Two-way fixed effects (TWF) method, while model (2) is estimated using the Interactive fixed effect (IFE) approach. Table A3 reports the full estimates.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

TABLE 5 | Predictive effects of ley area increase on total working hours for family and hired labour.

	Family labour (GW → T)		Hired labour (GW → T)	
	(1)	(2)	(1)	(2)
Log ley area	0.5653*** (0.0403)	0.5420*** (0.0238)	−0.1424* (0.0750)	−0.1801** (0.0581)
Controls	Yes	Yes	Yes	Yes
Farm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	3197	3197	3197	3197
R^2	0.6455		0.3026	

Note: Standard errors are in parentheses and clustered at the farm level. Model (1) assumes homogeneous effect, while model (2) assumes heterogeneous effect. Model 2 is our preferred estimates. Model (1) is estimated using the conventional Two-way- fixed effects (TWF) method, while model (2) is estimated using the Interactive fixed effect (IFE) approach. Table A4 reports the full estimates.
*$p < 0.1$.
**$p < 0.05$.
***$p < 0.01$.

Figures A1 and A2 present the distributional effect estimates (i.e., the point) for grassland area and ley area, respectively. Overall, the result reveals that the effect of an increase in either grassland area or ley area is heterogeneous across the entire quantiles of the outcome variables. Specifically, the result shows that the effect of an increase in either grassland area or ley area is negative at the lower quantiles of both milk yield and the cost of veterinary services, and negative across the entire quantile distribution of feed cost. The reduction in milk yield at the lower quantiles may strongly underline the observed negative effects at the average level and the lower quantile indices for the farm net income. This may indicate that the reduction in milk yield (and in turn milk revenue) associated with the uptake of more grass-based feeds offsets the feed cost-reducing effects of more grass-based feeds, leading to a negative farm net income effect. Finally, it is worth noting that the decline in the feed cost may have a positive effect on the environment through a decrease in greenhouse gas emissions associated with the production, processing and transportation of grain-based concentrate feed (O'Brien et al. 2014, 2016).

4.5 | Robustness Checks

We conduct several sensitivity analyses to check the robustness of our baseline estimates to different functional form specifications and assumptions. First, we adopt the Lewbel Two Stage Least Squares with fixed effects (Lewbel-2sls) moments-based approach (Lewbel 2012) to estimate our baseline regression model. The Lewbel-2sls estimator is used when valid external instruments are unavailable. The estimator exploits the heteroskedasticity in the observations to generate valid instruments to address the potential endogeneity, which in our case may be due to unobserved time-varying omitted variables that can influence farmers' uptake of grass-based feeding practices (Lewbel 2012; Baum and Lewbel 2019).

Furthermore, we set our baseline model in a linear dynamic framework by including a lag of the outcome variables as part of the model estimation. Here, we premise our model estimation on the assumption that past farm outcomes may influence farmers' future decisions to adopt grass-based feeding and, in turn, affect future outcomes. We estimate the dynamic linear panel model using the Generalised Method of Moments (GMM) approach proposed by Arellano and Bond (1991). We note that the estimator controls for endogeneity by using the first difference of the control variables and their lags as instruments in the estimation (Roodman 2009). Finally, we re-estimate our baseline model using the Double Machine Learning (DML) with least absolute shrinkage and selection operator (LASSO), as in Chernozhukov et al. (2018). We note that the LASSO method helps reduce dimensionality while incorporating all relevant control variables individually, as well as their interactions with other variables.

Figures 5 and 6 present the coefficient estimates by the estimators used. The point denotes the coefficient estimate and the vertical line denotes the 95% confidence intervals. Generally, all the estimators imply that an increase in either grassland area or ley area is negatively associated with both farm net income and fertiliser expenditure, and positively associated with total working hours. Taken together, the directions of the estimators are qualitatively akin to our baseline average estimates, which indicate that our findings are generally consistent across different model specifications and assumptions.

5 | Discussion and Conclusions

We examined the predictive effects of the uptake of more grass-based feeding practices (i.e., increase in grassland area or ley area) on economic, social and environmental dimensions of farm sustainability in Sweden. We used farm-level data on dairy farmers that covered the period 2002–2021. We adopted panel regression with fixed effects and panel quantile regression to analyse the average and the distributional effects, respectively. We also triangulated our findings using both static and dynamic regression approaches.

Overall, the findings at the average level imply that the uptake of more grass-based feeding practices is negatively associated with both farm net income and fertiliser expenditure, and positively associated with total working hours. This suggests that the uptake of more grass-based feeding practices

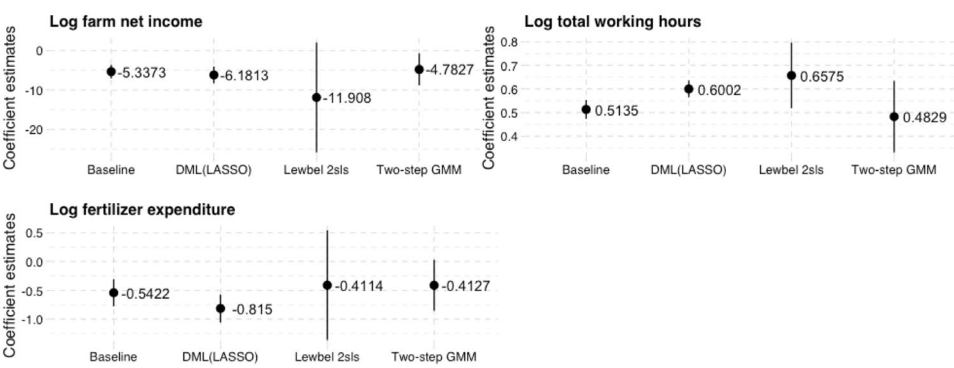

FIGURE 5 | Sensitivity analysis for the estimated coefficients of grassland area. Standard errors robust to heteroscedasticity and serial correlation at the farm level are reported for the Two-step GMM estimator. We also accounted for all the control variables as in Table 1, including the farm and year fixed effects in the the Two-step GMM estimations. The *p*-values of the Hansen J test are; farm net income: 0.985; total working hours: 0.4630; amount of fertiliser used: 0.347. Note that we apply the Windmeijer (2005) sample correction for the standard errors. For the Lewbel 2sls, the *p*-values for the Hansen J test are: farm net income: 0.402; total working hours: 0.233; and amount of fertiliser used: 0.772.

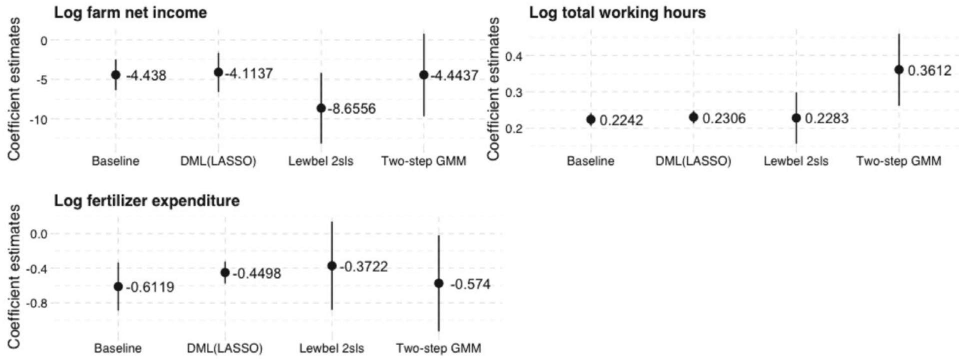

FIGURE 6 | Sensitivity analysis for the estimated coefficients of ley area. Standard errors robust to heteroscedasticity and serial correlation at the farm level are reported for the Two-step GMM estimator. We also accounted for all the control variables as in Table 1, including the farm and year fixed effects in the Two-step GMM estimations. The *p*-values of the Hansen J test are:; farm net income: 0.985; total working hours: 0.4630; amount of fertiliser used: 0.347. Note that we apply the Windmeijer (2005) sample correction for the standard errors. For the Lewbel 2sls, the *p*-values for the Hansen J test are: farm net income: 0.35; total working hours: 0.060; and amount of fertiliser used: 0.732.

has negative implications on both economic and social dimensions of sustainability, and a positive implication on the environmental dimension. The positive effect of the uptake of grass-based feeding practices on the environment is consistent with previous studies that found that the uptake of grass-based feeding practices has a positive effect on the environment through the reduction in GHG emissions or the decrease in the use of nitrogen fertiliser (Balaine et al. 2023; Mack and Kohler 2019).

By contrast, the negative effects of the uptake of more grass-based feeding practices on farm economic performance at the average level disagree with the findings of Balaine et al. (2023) and Mack and Kohler (2019); this could partly be due to the nature of the economic indicator used in the previous studies. That is, while we focused on farm net income per livestock unit, Balaine et al. (2023) considered gross income per livestock unit, and Mack and Kohler (2019) considered farm income without normalising by the number of animals, thus integrating farm size in the measure of farm income. Furthermore, the positive effect of the uptake of more grass-based feeding on total working hours suggests that farmers are likely to spend more time on the farm and less time on other equally important social activities. The results suggest that the increase in total working hours is due to increases in family working hours rather than the working hours of employees.

The results at the distributional level indicate that the effects are heterogeneous across the distribution of the outcome variables. Specifically, the findings reveal that the effect of the uptake of more grass-based feeding practices is negative at the lower quantiles of farm net income and positive at the upper quantiles. These findings confirm that our average effects masked the distributional effect estimates. This result corroborates the general knowledge that the average effect estimate obscures the distributional effects (Abrevaya and Dahl 2008; Koenker 2004; Roger et al. 2017). Moreover, the positive effects at the upper quantile distribution are consistent with previous studies (Balaine et al. 2023; Mack and Kohler 2019) that found that the uptake of grass-based feeding practices may have a positive effect on farm income. Furthermore, the distributional effect estimates indicate that the effect of the uptake of more grass-based feeding practices is positive and heterogeneous across the quantiles of total working hours. The results also suggest that the effect of the uptake of more grass-based feeding is heterogeneous and negative at the lower quantiles of fertiliser expenditure.

However, it is vital to note that, although reducing fertiliser use can have positive environmental effects at the farm level, the benefits in terms of reduced GHG emissions may not necessarily be realised when measured per litre or kilogram of milk produced. Moreover, an increase in grassland or ley area may imply a reduction in other land uses (e.g., cropping), which could lead to other environmental effects due to dynamic effects in the food system. Taking into account all sources of emissions, including emissions from land use changes, Lindberg et al. (2021) show that about 1.2 kg of CO_2-equivalent emissions per kg of milk is generated in Swedish high-yield dairy farms, and about 50% of the estimated emissions stem from feed production. This suggests that there is an opportunity for reducing emissions from intensive dairy farms, and grass-based feeding can play a role. In our study setting, we are unable to provide estimates of the benefits of adopting more grass-based feeding in terms of GHG emissions reductions per kilogram of milk produced due to data limitations.

On the policy front, the results highlight the trade-off (i.e., negative effect on economic and social aspects of sustainability, and positive effect on environmental dimension) associated with farmers' transition towards the uptake of more grass-based feeding practices in a typical Nordic country. The findings of this study also have important policy implications related to the current CAP 2023–2027 in the EU and Sweden. The changes in the CAP highlight the need for increased financial compensation for environmental support in pasture management, with compensation rising by up to 750 SEK/Ha (Government of Sweden 2023). However, the 500 SEK/Ha reduction in direct subsidy support offsets much of this increase. As a result, farmers maintaining pastures see little overall improvement, as the boost in environmental support is largely negated by the cut in direct payments. In addition, the environmental support for ley cultivation provided to reduce leakage of plant nutrients and stimulate sustainable cultivation has been removed.[3] A crucial aspect of this policy is that it might discourage more grass-based feeding among farmers. This suggests that to encourage farmers' uptake of more grass-based feeding practices would require policies that can adequately compensate farmers for the loss of farm income associated with the uptake of more grass-based feeding practices.

Furthermore, a complementary private market-based policy instrument in the form of a premium price for milk produced with more grass-based feeds can be explored (Schreiner and Hess 2017). This could potentially reduce the budgetary burden of increasing income support from the CAP and alleviate uncertainty associated with public policy changes, thereby incentivising farmers to adopt more grass-based feeds. However, a rigorous ex-ante evaluation is needed to better inform the design of such a market-based policy instrument and is an important task for future research. Besides advocating for financial policy instruments, non-financial policy instruments can also be considered. If not compensated, milk yield reduction and hence reduction in revenue is a major concern associated with higher forage feed rations, due to their lower nutritional value compared to higher concentrate feeds (Lindberg et al. 2021). To address this concern, policies supporting farmer knowledge on the production and usage of nutrient-rich forage diets, such as grass-clover silage, can minimise the milk yield losses (Karlsson et al. 2020).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Endnotes

[1] Although the stock density is 1.1 LU/Ha, this does not suggest that farms on average have considerable potential to increase grass-based feeding since the standard deviation (SD = 0.579) is less than the mean, indicating less variation in the data (McElreath 2018). Moreover, Tables 2 and 3 indicates that increases in stocking density is negatively associated with a decrease in farm net income and total working hours, but positively associated with increases in the fertiliser expenditure.

[2] The binscatter is a semi-parametric approach used to visualise bivariate relationships and for conducting informal specification testing (Cattaneo et al. 2019). Recent studies (e.g., Feigenberg and Miller 2022; García and Heckman 2023; Gerard and Naritomi 2021) have employed the binscatter approach to examine bivariate relationships in different contexts.

[3] Miljöersättning för vallodling-Jordbruksverket.se.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** jage70003-sup-0001-DataS1.docx.