Examining the policy-practice gap: the divergence between regulation and reality in organic fertiliser allocation in pasture based systems.

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Abstract

Slurry and animal manure generated from livestock production systems are typically recycled back to land to replace nutrients removed in products leaving the farm such as milk, meat and grass. Avoiding environmental losses of nutrients due to slurry spreading requires careful management, contingent on farmers following agronomic advice and policy regulation, yet, nutrient losses to water from agriculture continues to put a significant pressure on water quality. The objective of this study was to examine whether a policy-practice gap in slurry management exists on farms by identifying the factors that influence the decision to spread slurry, across the farm. To achieve this, a Heckman selection model was used to identify the drivers of slurry management using farm and field management records and soil information from commercial livestock farms combined with spatial datasets on landscape position. The main drivers influencing the decision to spread slurry were practical considerations relating to the structure and spatial arrangement of fields on the farm, such as proximity to farm yard, as well as landscape position. Field and landscape variables were also related such as slope, elevation, drainage capacity, soil type, presence of open ditches, and soil phosphorus (P) level. Fields with excessive soil P content had a high probability of receiving slurry in greater amounts, thus challenging the assumption that farmers use soil testing to guide slurry management, and identifying the main agri-environmental policy-practice gap and a need for better knowledge exchange in this area. Despite current policy, practical considerations override soil testing and these results showed that slurry management and allocation is rooted in the spatial arrangement of fields on the farm. The results indicated that farmer decisions are driven by factors that relate to the time, cost and labour involved in spreading slurry, indicating the need for water quality measures and policy to consider the practical constraints and considerations from the viewpoint of the farm.

Keywords: nutrients; policy; water quality; phosphorus

1. Introduction

Agricultural systems continue to put significant pressure on the environment (Groot et al., 2012) through the use of nitrogen (N) and phosphorus (P) in fertiliser, slurry and manures. Pasture based systems depend highly on grass as their main source of feed for livestock, and recycling of slurry to grazing and cut swards and the use of chemical fertilizers is essential to replace nutrients removed in products such as milk, meat and silage (O'Mara, 2008). When applications of slurry and fertiliser exceed crop demand this can cause unintended losses of nutrients to the environment (Kerebel et al., 2013), such as Green House Gasses and ammonia emissions, or N leaching and P runoff to water that leads to eutrophication. In the EU, nutrient losses to water are addressed under the Nitrates Directive (91/676/EEC) within the Water Framework Directive (WFD) (2000/60/IEC). The aim of the directive is to maintain "high" status where it exists and improve all other waterbodies to 'good' status by 2027.

Combined, the WFD and the Nitrates Directive (91/676/EEC) set the legislative frameworks for manure and slurry management on nutrient losses to surface and ground waters. Regulations are implemented at farm scale by placing a cap on stocking rates to limit the inputs of organic N to 170 kg N ha^{-1}, however, for P, the regulations are centred around farms maintaining a P balance (Amery and Schoumans,2014). In Ireland, farms must maintain a zero P balance at the farm gate through nutrient budgeting and adherence to Good Agricultural Practices (GAP) to protect water quality (S.I. no. 605 of 2017). These measures are founded on 'right rate', 'right time', 'right place' concepts in nutrient management which takes account of soil testing to avoid over-application, spreading too close to watercourses and before or during rainfall events to avoid incidental losses. Current regulation in Ireland also provides for a closed period between October and January during which application of chemical and organic nutrients is prohibited.

Despite these controls on inputs and practices, agriculture remains a pressure on water quality, indicating that a potential policy-practice gap exists within this topic and research has suggested that whilst policy is designed at national scale, nutrient management requirements to protect water quality are likely to be farm specific (Kelly et al., 2018). Soil and field specific nutrient management provides the best agronomic return and the least environmental risk, however, farm gate nutrient budgets indicating compliance with regulations can potentially mask agronomic underperformance or hotspots of environmental risk at field scale (Jordan et al., 2014; Thomas et al., 2016). Furthermore, even if farm gate balances are low an uneven distribution of nutrients across the farm can exist, (Roberts et al., 2017; Roberts and Johnston, 2015; Wall et al., 2012). This potential policy-practice gap opens when regulations operate at farm level, but farmers operate at field level (Micha et al., 2018) which research suggests should be considered as the management unit to avoid environmental losses (Dawson and Hilton, 2011; McDowell et al., 2015; Roberts and Johnston, 2015). As slurry represents the main P source at field scale (McDowell et al., 2015), its distribution across fields on the farm is important for economic and environmental farm efficiency and allocation based on crop requirements and uptake potential however, precise field-by-field distribution to mitigate diffuse pollution (Liu et al., 2018) and optimise production sustainably could be challenging due to the variety of production systems, land uses and spatial and structural variability on farms. For many farmers, however, this decision depends more on a combination of factors related to their perceptions of effective farm management (Turinawe et al., 2015) and are mainly driven by the structure and facilities of the farm, the interactions between fields, the goals of the farmer, as well as other factors like perceived usefulness (Monaghan et al., 2007).

Few studies are concerned with farmers' decisions regarding organic and inorganic fertilizer across the world (Micha et al., 2019; Osmond et al., 2015). They indicate a variety of factors that affect these decisions such as land characteristics, farmers' characteristics, farmers' views, attitudes and perceptions and policy instruments and regulations (Blackstock et al., 2010; Buckley, 2012; Chadwick et al., 2011; Daxini et al., 2018; George et al., 2018, Wall et al., 2012). In livestock systems, slurry and farmyard manure are an inevitable consequence of dairy and dry-stock production (Chadwick et al., 2011) and whilst the aim of slurry spreading is to recycle nutrient back to land (McCann et al.,

2007) management decisions are often based on individual decision-making that relate to farmers' perception of the characteristics of their fields (Lalor and Culleton, 2016; Micha et al., 2018).

The main objective of the study is to identify the extent to which a policy-practice gap exists in pasture based systems in terms of the regulation and advice provided for slurry spreading and the reality in terms of practice. Understanding this gap might give a better understanding of how organic fertilizers are allocated on grassland fields and provide further knowledge to improve nutrient management planning at field level. Altogether, this understanding could support the formulation of advisory tools and identify other barriers or requirements that could improve field nutrient distribution with a view to improved agronomic and environmental outcomes (Micha et al., 2017). To realise this objective this study used an integrated econometric approach to estimate the impact of a number of structural and spatial factors on a farmer's decision to use organic fertilizer on a field and on the amount of fertilizer allocated. The extent to which decisions were influenced by spatial and structural field characteristics was tested using high resolution empirical evidence derived from farm and field surveys conducted in three high status river bodies in Ireland.

2. Methodological framework

2.1. Study area

The study used data from an extended field survey conducted on 487 grassland fields, across 39 commercial farms, located in catchments representative of high status river bodies in Ireland (Figure 1). The survey collected detailed data at field level on organic and inorganic fertiliser inputs, physical and structural characteristics of the fields, and soil chemical and drainage characteristics. The survey included soil sampling and analysis to identify soil P, K, soil pH and organic matter content. Agronomic soil testing in Ireland uses Morgan's reagent to measure soil P and values are categorised into indices to indicate soil P availability for crop uptake. The P index system has four categories of Morgan's P values: Index 1 (0-3 mg L^{-1} deficient), Index 2 (low 3.1-5 mg L^{-1}), Index 3 (agronomic optimum 5.1-8 mg L^{-1}) and Index 4 (>8 mg L^{-1} excessive) that identifies excessively fertilised fields (Index 4) as well as those at optimum (Index 3) and deficient in P (Index 1 and 2). For further information on the field survey see Roberts et al. (2017). Spatial data collected included, the distance of a field from the farmyard, the distance from the nearest watercourse, slope, elevation and the presence of open drains at the perimeters of each field. The spatial data was combined with national maps of water courses and soil type, using ArcGIS to calculate the distance of each field to the nearest watercourse, and assign a drainage class to each field. Field's soil drainage class was extracted from digital layers of soil maps with areas delineated as well, moderately, and poorly drained. These categories are based on the Irish Soils Information Systems (ISIS) (http://gis.teagasc.ie/isis/) and describe the soils potential to drain excess water through the profile, and indicate the suitability of soils for livestock and traffic, as well, as potential for overland flow and water movement. A complete list of the variables used for the purposes of this study is given in Table 2.

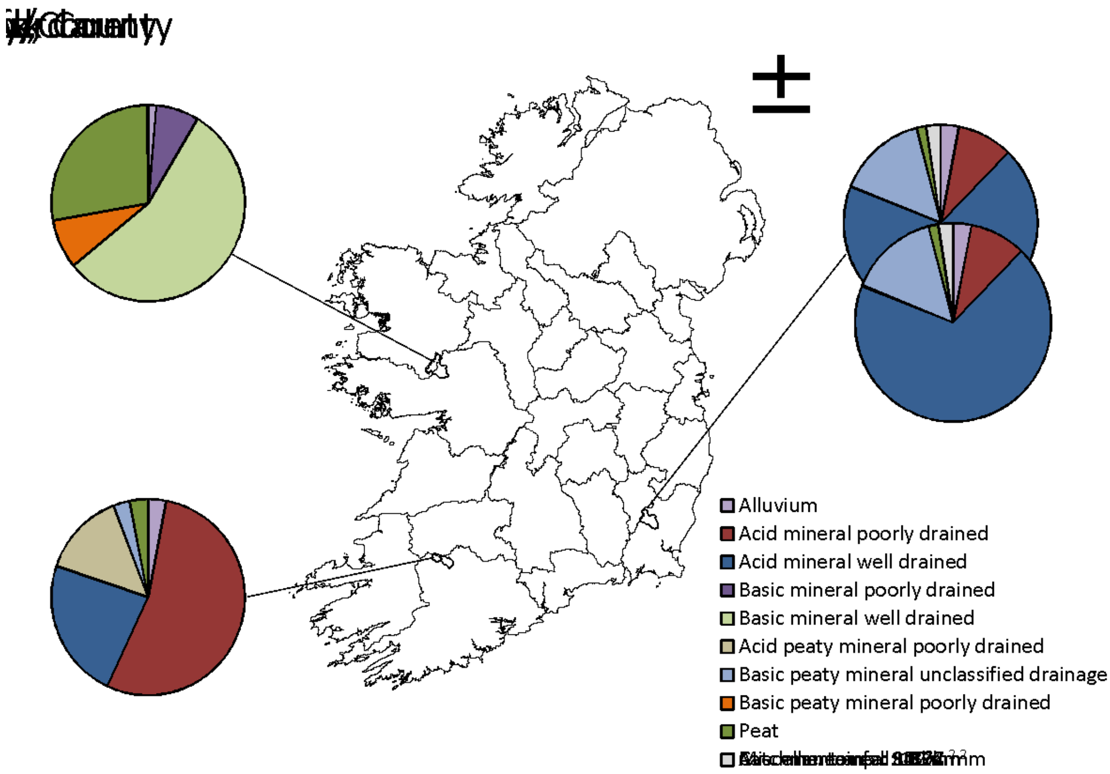

Figure 1. Location and description of catchments where farm surveys were conducted.

Table 2: Description of variables used in the study

Variable	Type	Description	Unit
Amount of slurry	Numeric	The amount of slurry allocated on a field	Tonnes
Elevation	Numeric	Field elevation above sea level	Meters
Farm yard manure	Numeric	The amount of farm yard manure allocated on a field	Tonnes
Organic matter content	Numeric	The % of organic matter	%
Distance to farmyard	Numeric		Meters
Slope	Numeric		%
Area	Numeric	The utilized area of a field	Hectares
Morgans P	Numeric		ppm
pH	Numeric		
Land use	Nominal		
Natural grassland		Field is out of production and used as a natural habitat	
Grazing		Field is used for grazing only	
1 Cut & grazing		Field grass is cut for silage once and then field is used for grazing	
2 cut		Field is used for silage only	
2 cut & grazing		Field grass is cut for silage twice and then field is used for grazing	
Neighbouring field receives slurry	Binary		YES/NO
Field receives manure	Binary		YES/NO
Soil is organic	Binary		YES/NO
P index 4	Binary	Field has a P index 4	YES/NO
Open drains	Binary	Presence of open drains around the borders of a field	YES/NO
Soil use potential		Soil drainage category: peaty soils, poorly drained, moderately drained, well drained	Ordinal 0-3

2.2 Choice of variables

The conceptual framework of the study is to identify which field characteristics are most closely associated with the decision to spread slurry on the farm. The field characteristics include physical attributes namely, slope, elevation and drainage capacity (soil use potential) as well as structural characteristics such as field size and distance from the farmyard. Information on field management and land use system were also included.   The soil chemical properties in each field were captured from soil sampling carried out by Roberts et al. (2017) and variables describing soil P level (Morgan's P values) and P Index were included as measures of a fields requirement for P or otherwise. Information on soil organic matter content (% OM) was included to identify fields that would be classified as ‘Peaty’. This was included as a variable in the model as current guidelines permit a maintenance rate only of P on this soil type due to poor nutrient retention and high risk of P loss (Wall and Plunkett, 2016; Daly et al., 2002; González Jiménez, et al. 2019; Gonzalez Jiménez et al. 2018). These particular characteristics were chosen as factors that potentially influence farmer decision to allocate slurry on fields, and the selection was informed by, consultations with Teagasc advisors and other knowledge transfer agents, who monitor and evaluate slurry allocation of pasture fields. Informal conversations with farmers in these catchments took place during the survey, and validated the choice of the variables. These discussions also indicated the neighbouring field receiving slurry as a potential influential factor, as well as the existence of open drains around the field.

2.3 Empirical model

The impact of the factors investigated on the amount of slurry a field receives is estimated using a linear regression model:

$$y = X\beta + \varepsilon$$

Where y is the amount of slurry a field receives, X is a vector representing the factors influencing y, β is a vector of parameters to be estimated, and ε is the unobserved error term.

According to Greene (2004) when using observational data, the sample may not be completely random as observations may be self-selecting themselves. Following this suggestion, in this study, before examining the amount of slurry a field receives, we have to examine if the field is first selected for slurry application. Therefore, the theoretical framework of the model used to estimate slurry application is specified as:

$$y_i = X_i'\beta + \varepsilon_i \qquad (1) \qquad z_i = W_i\gamma + u_i \qquad (2)$$

where z_i is a binary choice:

$$z_i = \{0 \quad if \;\; slurry\ applied\ on\ the\ field = 0 \;\; 1 \quad if \;\; slurry\ applied\ on\ the\ field > 0 \qquad (3)$$

and y_i represents the amount of slurry applied on a field with:

$$y_i = \{\beta_1 X_\iota + \varepsilon_\iota \qquad if\ z_i = 1\ \ unobserved \qquad if\ z_i = 0 \qquad (4)$$

y_i only observed when $z_i = 1$, and ε_ι and u_i are error terms which follow a bivariate normal distribution:

$$\lfloor \varepsilon_i\ u_i \rfloor \tilde{} N\left[\sigma^2\ \ \rho\sigma\ \rho\sigma \quad 1\right] \qquad (5)$$

where N denotes normal distribution and ρ is the correlation coefficient: $\rho = corr(z_i, \varepsilon_\iota)$.

In the initial specification of the Heckman selection process equation (1) we use a linear regression model to estimate equation (1) and a binary Probit regression to estimate equation (2). Given that we have the bivariate normal distribution described in equation 4, the two models are inserted in the Heckman selection model as follows:

$$E\left[z_i > 0\right] = X_i\beta + \theta\left[\frac{\varphi(\omega\gamma)}{\Phi(\omega\gamma)}\right] \qquad (6)$$

$$E\left[y_i is\ observed\right] = E\left[z_i^* > 0\right] = E\left[\omega_i\gamma + u_i > 0\right] = X_i\beta + E\left[\omega_i\gamma + u_i > 0\right] = X_i\beta + E\left[u_i > -\omega_i\gamma\right]$$

As (Greene and Hensher, 2010) notes:

$$E\left[u_i > -\omega_i\gamma\right] = \rho\sigma_\varepsilon\lambda_i\left(\alpha_u\right) \qquad (8)$$

Where: $\alpha_u = -\omega_i\gamma$, $\lambda\left(\alpha_u\right) = \frac{\varphi(-\omega_i\gamma)}{\Phi(-\omega_i\gamma)}$. So, the conditional mean in the model becomes:

$$E\left[y_i is\ observed\right] = E\left[z_i^* > 0\right] = X_i\beta + \rho\sigma_\varepsilon\left[\frac{\varphi(\omega_i\gamma)}{\Phi(\omega_i\gamma)}\right] = X_i\beta + \rho\sigma_\varepsilon\lambda_i\left(\alpha_u\right) = X_i\beta + \beta_\lambda\lambda_i\left(\alpha_u\right) \qquad (9)$$

And finally:

$$y_i|z_i^* > 0 = E\left[z_i^* > 0\right] + v_i = X_i\beta + \beta_\lambda\lambda_i(\alpha_u) + v_i \qquad (10)$$

We estimate the Heckman selection model using maximum likelihood estimation. In the maximum likelihood estimation, ρ is not directly estimated but a transformed sample correlation coefficient is estimated instead using Fishers transformation (Fisher, 1915). According to Fisher (1915), if y and z are normally distributed and

$$Corr\left[z_i\right] = \rho$$

then a variable *z* can be estimated:

$$z = \rho\ = \frac{1}{2}\ln ln\ \left(\frac{1+\rho}{1-\rho}\right) \qquad (11)$$

where *ln* is the natural logarithm function and *atanh* is the inverse hyperbolic function. The Fisher transformation for sample correlation is preferred because it allows for all positive and negative numbers to represent valid values for correlations and because it has a near-constant variance for all values of ρ (Buis, 2011; Cox, 2008).

2.4 Marginal effects

Marginal effects of the Heckman model are the indirect effects on the condition that the independent variable also appears in the selection equation. This is because a change in X_i changes both the mean of y_i and the probability of an observation being in the sample. So, the conditional marginal effect of X on y is:

$$\frac{\partial E[y_i|z_i^*>0]}{\partial x_{ik}} = \beta_k - \gamma_k\left(\frac{\rho\sigma_\varepsilon}{\sigma_u}\right)\delta_i(\alpha_u) \qquad (12)$$

Where $\delta_i(\alpha_u) = [\lambda_i(\alpha_u)]^2\ - \alpha_u\lambda_i(\alpha_u)^4$

As the selection equation is estimated by a binary probit, we are also able to estimate the partial effects of the changes of w on the probability of the outcome:

$$\frac{\partial P(z_i=1|w_i)}{\partial w_i} = \frac{\partial E(z_i|w_i)}{\partial w_i} = \varphi\left(w_i'\gamma\right)\gamma \qquad (13)$$

2.5 Validation of results

Due to the limited literature on the subject, once the results of the econometric model were produced and to facilitate the interpretation of the results, further short informal interviews were conducted with a number of farmers and extension agents that aimed at commenting on the quantitative results. In total 10 farmers and 3 extension agents were interviewed. The outcomes of these interviews were incorporated in the discussion of the empirical results.

3. Results

3.1. Statistical summaries

The statistical summaries of the continuous variables and the frequencies of the categorical variables used in the Heckman model for slurry allocation are presented in Table 3. Mean and standard deviation (SD) are presented to show the distribution of the values of the mean. In these data, the SD can be used to express a large variability of the values of certain variables between the fields. Farm fragmentation is a possible practical explanation for high SD of “distance from farmyard”. Regarding the SD for FYM and slurry the values are assumed reasonable as slurry and FYM are expressed in tonnes, (not t/ha) and the sample fields have different sizes and land uses. The SD of “slurry” and “FYM” indicate an important variability of slurry and FYM allocation across fields, which is partly the motivation behind this study. The wide variation in Morgan’s P values indicates an uneven distribution of nutrients across farms with some fields receiving repeated applications of nutrients in excess of crop demand, largely due to lack of soil testing.

Table 3: Means and standard deviations of the numeric variables used in the Heckman model for field slurry allocation

Variable	Mean	SD
Continuous variables		
Amount of slurry (t)(dependant variable)	7.153	10.327
Elevation (m)	136.307	74.321
Farm yard manure (t)	1.026	3.325
Organic matter content (%)	16.514	11.712
Distance to farmyard (m)	896.278	1482.734
Slope (%)	5.638	4.059
Area (ha)	2.890	1.641
Morgan's P (ppm)	159.707	63.481

3.2. Heckman selection

The results of the Heckman model and the relevant marginal effects are presented in Table 5 and Table 6. Table 5 presents the coefficients and marginal effects of the binary probit selection model and Table 6 presents the coefficients and conditional marginal effects of the truncated linear regression model. The Heckman selection procedure censored 262 observations and the $Ath\rho$ was statistically significant at the 1% level meaning that the error terms of the two regressions were correlated and the Heckman model process corrected the sample for selection bias. We interpreted the results of both the selection and the truncated regression model separately, as the decision to allocate slurry on a field was considered critical and equally important to the decision on the amount of slurry applied once a field is selected for spreading.

Table 4: Frequencies of the categorical variables used in the Heckman selection model.

Categorical variables	Frequency	Average amount of slurry received (t)
Field receives slurry	53.8*	15.52
Land use		

Natural land	2.05	0.82
Grazing	63.86	3.47
1 Cut & grazing	24.64	13.11
2 cut	3.7	17.86
2 cut & grazing	5.75	7.33
Neighbouring fields receive slurry		
YES	55.24	11.25
NO	44.76	1.84
Field receives FYM		
YES	24.85	9.58
NO	75.15	5.84
Soil is organic		
YES	46.20	3.86
NO	53.80	7.20
P index 4		
YES	26.43	6.33
NO	73.57	9.58
Open drains around field		
YES	26.49	8.12
NO	73.51	6.27
Soil use potential		
Peaty soils	6.78	3.64
Well drained	53.39	9.29
Moderately drained	28.75	9.32
Poorly drained	11.09	5.36

*This value is generated by the Heckman selection process through the censoring of observations

Table 5: Coefficients and conditional marginal effects of the binary probit on slurry application on a field (st.errors in brackets)

SELECTION		
	Coefficient.	dy/dx
Land use		
Natural land	Omitted	Omitted
Grazing	1.264 (0.458)***	0.246 (0.062)***
1 Cut & grazing	2.770 (0.499)***	0.618 (0.074)***
2 cut	3.509 (0.626)***	0.760 (0.090)***
2 cut & grazing	1.917 (0.540)***	0.411 (0.098)***
Elevation	0.001 (0.001)	0.000 (0.000)
Distance to Farmyard	-0.111 (0.000)***	-0.111 (0.000)***
Neighbouring field	1.749 (0.171)***	0.350 (0.022)***
FYM (YES/NO)	0.763 (0.192)***	0.153 (0.037)***
Organic soil (YES/NO)	-0.725 (0.274)***	-0.145 (0.053)***
Slope	-0.026 (0.025)	-0.005 (0.005)
Area (ha)	0.124 (0.046)***	0.025 (0.009)***

P index 4 (YES/NO)	0.358 (0.223)*	0.072 (0.044)*
Open drains (YES/NO)	0.279 (0.183)*	0.056 (0.036)*
Constant[1]	-4.931 (1.219)***	

Table 6: Estimated coefficients and conditional marginal effects of the truncated linear regression model on the amount of slurry (tonnes) allocated to a field (st. error in brackets).

Atanh *ρ:* 0.029 (0.240)***		
	Coefficients	dy/dx
Land use		
Natural land		
Grazing	*3.692 (2.081)**	*3.461 (1.974)**
1 Cut & grazing	*5.082 (2.524)***	*4.656 (2.770)**
2 cut	3.770 (3.297)	3.289 (3.387)
2 cut & grazing	*19.369 (2.955)****	*19.041 (2.892)****
Distance to Farmyard	-0.011 (0.000)***	-0.011 (0.000)***
Slope	-1.267 (0.207)***	-1.263 (0.208)***
FYM (tonnes)	-0.705 (0.295)**	-0.705 (0.295)**
Organic matter content (%)	-0.312 (0.116)***	-0.312 (0.116)***
Area (ha)	0.362 (0.384)	0.645 (0.396)
Morgan's P	0.008 (0.009)	0.008 (0.009)
Soil use potential		
Peat		
Well drained	0.948 (2.814)*	0.942 (2.230)*
Moderately drained	0.897 (2.811)*	0.893 (2.102)*
Poorly drained	-0.106 (2.396)*	-0.103 (2.429)*
cons	30.550 (8.999)***	
Significant at:*** 1% , **5%, *10%; Number of observations=487; censored obs=262		

4. Discussion

4.1. Decision to allocate slurry on a field

The results presented in Table 5 confirm that all land uses had a significant and positive correlation to the probability of a field receiving slurry[2], with fields used for 2 cuts of grass for forage (without

[1] The "constant" coefficient expresses the probability of a field receiving slurry if all variables were held constant, meaning there was not change in any of them. The probit model does not produce a marginal effect for the constant.

[2] The marginal effects, in this case, express the increase in the probability of the filed receiving slurry, if the land used changed from natural land to one of the other uses. The probability of "natural land receiving slurry is assumed to be 0.

grazing), having the highest impact (76%). Grazing only areas had the smallest impact (25%). Farmers and extension agents confirmed that it is less likely that slurry would be applied on a field used for grazing as slurry contaminated grass is less attractive to grazing animals. This finding is consistent with the increased demand for additional manure amendments where fields are managed for two cuts of grass in the absence of grazing deposition. Adjusted fertilisation is necessary to produce sufficient quality grass silage as part of a sustainable grass based livestock system for over winter fodder (Sheil et al., 2015).

The probability of a field receiving slurry was positively correlated with the field having at least one neighbouring fields receiving slurry as well (35% increase). Farmers and advisors have explained that this is an expected farm management practice; as it is related to time management and ease of transport of slurry, particularly on fragmented farms. As well as fuel cost savings, emptying slurry tanks quickly is a priority for the farmers (Chadwick et al., 2011), as is time management and minimization of labour and fuel cost savings so, as explained: “a farmer would transport slurry towards that direction and spread it to all the fields that are there….”. Similar reasons were given as the main explanation for the positive correlation between field receiving slurry and the area of the field (2.5% increase); as larger fields are easier to spread increasing efficiency.

As expected, the probability of a field receiving slurry was positively correlated with the probability of it receiving farm yard manure, a result that is confirmed in recent national fertilizer application studies (Wall et al., 2016). In addition, increased soil P index (P index 4) was positively correlated to the field receiving slurry (7%), regardless of the fact that national legislation and nutrient management advice do not recommend this practice. The explanation can be related to the lack of knowledge and information farmers have on the P content of their fields and on the management of these fields. In particular, in further discussions, it transpired that farmers may not be aware of the P index of their soils and continue their “business as usual” practices of allocating slurry to the field (Daxini et al., 2018). In addition, farmers and advisors mentioned that although legislation recommends avoiding spreading fertilizers to index 4 fields, this is often interpreted by farmers as referring only to chemical fertilizers. These results suggest that, practical considerations related to labour requirements, cost, and time management may override legislative issues, particularly if farmers consider that they are compliant based upon farm level reporting requirements, such as farm-gate P balances. This is borne out by the negative correlation between the distance to farm yard and the decision to put slurry on a field (11.1%), explained in further discussions about common practices used by farmers particularly when the farm extends at large distances from the farm yard. Typically, farmers would start slurry spreading at fields nearest to farm yard to save transport and labour costs and then gradually expand spreading on fields further away, often without considering whether slurry is evenly distributed across their farm. The presence of open drains or ditches also had a positive correlation with the probability of field receiving slurry increasing it by 5.6% which indicates that improving soil drainage also improves the field's trafficability and lending itself to slurry allocation. This relatively low probability could indicate that farmers are aware of the risks to water quality associated with open drains, however, even a low level of mismanagement by few or even one farmer could results in nutrient transfer to ditches and small streams (Daly et al., 2017).

4.2. Amount of slurry allocated to the selected fields

The truncated regression of the Heckman model provided the correlations and marginal effects of the examined factors on the amount of slurry allocated on a field, conditional to the selection of the field for slurry application (Table 6).

For land use systems the omitted variable was "natural land" that is, effectively, not expected to receive any organic fertilizer. Therefore, interpretation of the marginal effects for land uses refers to this variable. Three out of the four grazing systems were positively correlated with the amount of slurry received. As the slurry received by natural land is 0, this was an expected result, and the marginal effects shown in table 6, indicate by how much the amount of slurry would increase, if the land use changed. Specifically "grazing", "1 silage cut" and grazing" and "2 silage cuts and Grazing", increased the amount of slurry a field receives by 3.4, 4.6 and 19 tonnes respectively (table 6). This was an expected result as land used for silage production has higher nutrient requirements than land use for grazing only (Lalor and Culleton, 2016). The result was verified by farmers and advisors in follow up conversations. Similarly to the choice of field, silage cuts are perceived as more fertilizer demanding, while the amounts of slurry on "grazing only" fields are expected to be lower compared to silage production fields and should be limited, as grass contamination may reduce grazing rates. Equally, grazed fields are receiving direct input rates based on livestock units and so farmers are more likely to consider a reduced input requirement on that basis. Also, as the bulk of slurry is produced from animals consuming silage during the overwinter period, it has a high K level better suited for silage ground over grazed land (Forrestal, 2018).

Distance from farmyard decreased the amount of slurry received. Specifically an increase of 100 meters in the distance from the farmyard would decrease the amount of slurry by 1.1 tonnes (Table 6). As explained by farmers and advisors, especially on fragmented farms that need to spread over large distances, the distance of a farmyard to the field plays a role in slurry allocation decisions. For convenience and time-saving reasons farmers distribute slurry starting at the fields closer to the source and extend the distribution to more remote fields only if necessary. Furthermore, the amounts received in remote fields may be lower due to the reluctance of farmers to transport slurry far from farmyard more than once (1 load).

An increase in the amount of FYM received by 1 tonne, decreased the amount of slurry by 0.7 tonnes. Two explanations can be given for this result: a) as FYM and slurry are organic products of the same farm, the total amount of slurry produced is lower as FYM production increases and b) although their N and P content is different, both are organic fertilizers and their use is complementary, hence use of one decreases the use of the other (Wall et al., 2016). Farmers confirmed in the follow-up interviews that FYM and slurry are both considered on-farm produced organic fertilizers with similar potential, and their difference in N and P content is rarely taken into consideration. Related to this, it is important that famers are aware of the nutrient content of their slurry. Forrestal, (2018) reported large nutrient variability in slurry with a 17-, 11- and 15-fold difference in N, P and K respectively between high and low samples. Dry matter content is considered a reasonable indicator of N, P and K and can be calculated using a slurry hydrometer or by sending samples for laboratory analysis.

Slope was negatively and significantly correlated with the amount of slurry received by selected fields, with 1% increase in slope reducing slurry input by 1.26 tonnes. Under the WFD provisions, farmers are advised to put minimum fertilizers onto sloping land, as this reduces the risk of P run-off, and this recommendation may be a possible explanation for this result. Additionally, farmers have explained that as slope increases the land is harder to reach and to spread slurry on. So, similarly to remote fields, the amounts of slurry received by sloping fields may be lower due to farmer's aversion to transporting and spreading slurry to those fields more than once. This may be an indication of awareness of farmers with regard to spreading on slopes. An additional factor may also relate to an increased fuel cost or labour challenge of spreading in these harder to reach areas. There was also a significant negative correlation between distance to the nearest watercourse and amount of slurry received by selected fields, meaning that 1 m increase in the distance of the field from the watercourse reduces the slurry received by 0.03 tonnes. This may be indication of the effectiveness of knowledge transfer and some adherence to good agricultural practice, or that watercourses are often located downslope in the landscape

High % organic matter (Peaty soils) was negatively correlated with slurry amounts (0.31 tonnes).In relation to nutrient inputs, farmers are advised to manage high organic matter and peaty soils differently from mineral soils. Soils that are high in organic matter have poor P retention, such that applied P in the form of either slurry or fertiliser becomes immediately available for crop uptake and cannot be fixed or assimilated into the soils for uptake later on, in the way that mineral soils behave. Therefore the current agronomic advice on these soils is to apply maintenance rates of P and only during the growing season, largely due to the increased risk of loss to neighbouring waterbodies if P is applied and not immediately taken up by grass (Daly et al., 2001; Wall et al., 2016). The P index is not prescribed for soils with >20% organic matter because the concept of P build-up does not apply to these soils as they are unable to retain added P,(González Jiménez et al., 2019)and so only maintenance of P to meet crop requirements < P3 is permitted. Finally, Morgans' P[3] did not have any statistically significant impact on the amount of slurry receive by a field, although the selection model indicated that index 4 fields are more likely to receive slurry (Table 5).

5. Conclusions

[3] The lack of statistical significance indicates that there is no correlation between an increase in the Morgans' P and the amount of slurry allocated in a field. This result does not confirm that Index 4 fields receive the same amount of slurry as other fields; it shows that the slurry a field receives is not affected by the Morgan's P.

This study used an integrated econometric modelling approach to estimate the impact of a number of structural and spatial factors on a farmer's decision to spread slurry and on the amount of slurry spread at field scale on Irish farms. The model used field level nutrient management and land use information collected during a farm survey coupled with soil and landscape information from the catchment of the surveyed farms. The results from the modelling approach identified the policy-practice gap in that farmer decisions to spread slurry were highly influenced by practical considerations at field level and field characteristics, and not as heavily influenced by soil testing or agronomic advice as previously assumed. If decisions are made at field level, then this does not align with policy design and regulations that are implemented at farm scale. The model results indicated that farmer knowledge and experience of field conditions and landscape position was a driver in their decisions to spread slurry and the amounts of slurry spread. The implications for policy are that farm level regulation does account for uneven distribution of nutrients across the farm which may perpetuate losses to water in vulnerable areas and a zero P balance at the farm gate to satisfy compliance may not realise the improvements in water quality that are anticipated from these measures. Although, Good Agricultural Practice (GAP) measures on farms seeks to avoid nutrient losses to watercourses this study has indicated that local field and landscape conditions are a significant driver in slurry distribution across the farm.

Despite the current advice to spread slurry based on STP, the results from this study have indicated a high probability for spreading on high soil P fields on the farm If that field soil conditions and practical consideration over-ride soil testing and P level, then these influences on slurry spreading should also be considered in land use planning on the farm. For example, if fields nearest to the yard are more likely to receive more slurry, then the land use on these areas should be adapted to remove more P in offtakes, e.g. silage, or fodder crop, tillage. Whilst there are obvious challenges for farms to empty slurry tanks within a short window for slurry spreading after the closed period, these could be overcome by integrating a grazing management with even distribution of slurry across the farm.

These model results also indicated that farmer decisions are firmly rooted in the spatial arrangement of fields across farms and practical considerations. These include factors related to convenience of operations including time and labour, over a more spatially targeted approach to nutrient management. This study has revealed a policy-practice gap where farm level accounting to satisfy compliance requirements may be indirectly perpetuating mismatches in nutrient management strategies. Farmers must be convinced of the benefits to support a shift from a business-as-usual approach to one that might incorporate additional effort. Fertiliser is among one of the key agricultural inputs over which a farmer has a choice with more efficient manure management a key strategy including maximising slurry nutrient value to offset expensive chemical fertiliser inputs. The benefits and risks of current land spreading strategies must be communicated more concretely with farmers.

As operations may continue to intensify, it is becoming increasingly important to manage nutrient cycles to guarantee the sustainability of the system into the future. While soil testing is a first stop to managing nutrients, as yet, there is limited evidence that farmer decisions for slurry spreading are motivated by STP results. As part of the post-2020 CAP, an electronic Farm Sustainability Tool is proposed to be made available by Member States to farmers. This tool is expected to provide on-farm decision support of nutrient management functionalities. The platform is anticipated to exhibit high interoperability such that additional on-farm or e-governance applications can be added. Coupling information with economic benefits, even indirectly, could support a transition towards more effective nutrient management. Finally, on-going contact with advisory services is recommended as regular contact with an advisor, is important when considering slurry allocation as part of a farm nutrient management planning.

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