School of Geography and Environmental Science

BSc Environmental Science with DPP

Investigating optimal dairy slurry application – limiting environmental pollutants while maximising efficient agronomic nutrient utilisation

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Abstract

Farmers are often unaware of the nutrient content available and their slurry, risking over or under application. Nitrogen (N), phosphorus (P) and potassium (K) are found in slurry and are all essential for plant growth. If applied efficiently, slurry can be both agronomically and economically beneficial to farmers (reducing artificial fertiliser application and cost). It is also important that farmers are aware of their slurry nutrient content as over-application of P can cause water quality to decline and lead to eutrophication of local watercourses.

This report aims to assess if four dairy farms in the Mournebeg catchment area of Castlederg, Co. Tyrone, are utilising slurry efficiently to produce good quality grass to cut for silage in the late spring/early summer without contributing to diffuse pollution.

A gravity hydrometer was used to measure the dry matter content of two slurry samples taken from each farm after the first and second cut of silage, which was then converted to N, P and K values in kg/m^3. Using each farmer's current slurry spreading rate, the amount of N, P and K applied per hector (ha) was calculated. These amounts were compared to DAERA's slurry spreading and nutrient application limit through the Nutrient Action Plan (NAP) 2019. In addition, farmers' current supplement fertiliser amounts on top of the slurry were considered, and the total nutrient value applied per ha was also compared to DAERA's NAP.

It was observed that the farmers in the study are not effectively using their slurry as a fertiliser resource. It was concluded that soils with a P value of 4 should receive a 33m^3/ha application of high dry matter content and a 50m^3/ha application of low dry matter percentage slurry. Grass N requirements would still be met while reducing overapplication of P. Before any recommendations to increase slurry application can be made, the P-value of each farms soils must be known as not to risk an overapplication of P to soils and therefore to risk P losses to waterways.

1. Introduction

Slurry is a mixture of faeces and urine produced by cattle housed in the absence of bedding (Haygrarth & Jarvis, 2002; Warren *et al.* 2008). Slurry is accumulated during the winter months when dairy cows are housed due to poor weather and farmers protecting soil structure and damage from trampling (Holden *et al.* 2004; Warren *et al.* 2008). Farmers spread slurry on their fields, being harvested for silage as an organic fertiliser between late autumn and early spring (Wild, 1993). The responsibility of collecting, storing and utilising slurry appropriately then falls to the individual farmer (Warren *et al.* 2008)

If slurry is applied appropriately, it can be an agronomic asset to farmers, as cattle slurries supply essential plant nutrients (Wild, 1993). Pratt 1982 (as cited in Araji *et al.* 2000) showed that manure applied at an appropriate rate covered the total nitrogen (N) needs of crops while also supplying a more than adequate amount of phosphorus (P) and potassium (K) (Araji et al, 2000). In addition, manure also increases water infiltration rates in soils, reducing nutrient leaching and maintaining soil structure to reduce soil erosion (Araji *et al.* 2001; Haygrarth & Jarvis, 2002; Naden *et al.* 2010). The nutrient content of dairy slurry depends on the cattle diets, the age of the cow and the amount of bedding used (AHDB 2021).

Slurry can be economically beneficial to farmers if it is utilised efficiently, allowing farmers to cut down on artificial fertiliser applications and costs. This is becoming increasingly important as, over the last 12 months across the United Kingdom, fertiliser prices have increased rapidly due to rising energy costs and supply across Europe (Agriland, 2021; Teagasc 2022). Nitrogen fertiliser has increased in price from £0.20 per kg (£200 per tonne) in spring 2021 to £0.70 per kg (£700 per tonne) by autumn 2021, with phosphate and potassium prices also increasing by over 70% over the same period (FarmingUK, 2021).

However, dairy slurry must be appropriately managed to act as a suitable fertiliser while not being a potential pollutant. Maintaining agronomic production in agriculture while decreasing diffuse and atmospheric pollution is a problem faced worldwide (Gibbons *et al.* 2014).

Cattle slurry can contribute to atmospheric pollution (Naden *et al.* 2010; Smith and Williams 2016), as N is lost into the atmosphere through volatilisation in ammonia and nitrous oxide from the surface of manures (Warren *et al.* 2008). Slurry can also be a source of diffuse water pollution (Haygrarth & Jarvis, 2002; Holden *et al.* 2004; Smith and Williams 2016; Adenuga *et al.* 2018).

Phosphorus plays a significant role in photosynthesis, respiration, energy storage and cell division and enlargement (Mullins 2009). However, an excess of phosphorus threatens water quality. P inputs from agriculture are sufficient to maintain eutrophic conditions in waterways (Tunney *et al.* 1997). A surplus of P inputs to waterways (from over application to soils) threatens water quality. It increases biological productivity, which leads to eutrophication and a deterioration of water quality (Kleinman *et al.* 2011; Thomas *et al.* 2016). Agriculture contributes to more than 20% of water pollution incidents in Northern Ireland (Adenuga *et al.* 2018) and over 70% of the yearly P load to Lough Erne and Lough Neagh (McConnell *et al.* 2016). A report published by AFBI in 2020 showed an excess of 10,300 tons of P in Northern Irish soils in 2017, with a total of 1,530 tons of P lost to watercourses, 62% of this P originating from agricultural sources (AFBI 2020). P losses harm both farmers and the environment, with farmers losing economically and water quality deteriorating (AFBI 2020).

Therefore, it is beneficial for farmers to test their soil for available nutrients, meaning fertilisers are applied based on plant nutrient requirements, mitigating nitrate leaching (Hooda *et al.* 2000). Slurry application rates should not exceed the crop requirements (Hooda *et al.* 2000; Schoumans *et al.* 2014). Soil should be sampled every four years to ensure the critical level of P is maintained in soils (Johnston 2005, DAERA n.d.).

Dairy farms were chosen for this study as, according to DAERA, in 2020 there were just above 300,000 dairy cows in Northern Ireland, and the country's largest gross output in agriculture was milk, at 30%. (DAERA, 2020b) This made the dairy industry the largest agriculture sector in Northern Ireland and, compared to other agricultural sectors, contributes a significant amount to the Northern Irish economy (Adenuga *et al.* 2018).

Smith and Williams estimated in 2016 that Northern Ireland's total output of undiluted slurry in dairy farms was 3.30 million tonnes (Smith and Williams 2016), with one dairy cow producing around 35-57 litres of manure daily (Warren *et al.* 2008). With increasing dairy herd sizes comes an increasing amount of excess nutrients being applied to land by slurry, increasing the risk of nutrient runoff to waterways (Adenuga *et al.* 2018).

Manure spreading in Northern Ireland is therefore restricted, and the closed period prohibits farmyard manure from being applied from 31st October to 31st January (DAERA 2020a). DAERA's Nitrate Action Programme (NAP) states that no more than 50m^3/ha of organic manures will be applied in one application from March to September. The maximum nitrogen limit is 170kg N/ha annually (DAERA 2019). However, if soil test results show a high P-value already contained in soil (meaning an index of 2 or above), no more than 33m^3/ha of dairy slurry (41kg P/ha) should be applied (DAERA 2020c). In Northern Ireland, compliance with the Nitrates Action Programme is compulsory for farmers (Cassidy *et al.* 2019). While N limit levels are quantifiable, acceptable P level application rates from slurry have not been established (Mullins 2009).

It has been observed that farmers do not take full advantage of the nutrients contained in dairy cow manure as a fertiliser for crop growth due to the uncertainty surrounding the nutrient content of manure (Organisation for Economic Co-operation and Development, 1989; Haygarth and Jarvis, 2002). For most farmers, slurry spreading is seen as necessary nutrient recycling, while for others, it is seen as a waste management issue (Holden *et al.* 2004). When slurry is applied to land, the nutrient content and fertiliser content are often unknown (Scotford *et al.* 1998). As farmers tend to underestimate the nutrient value of their slurry, they then prefer to use an excessive amount of slurry that is required (Tunney *et al.* 1997). The excess N and P not assimilated by crops is then available to be released into freshwater courses (Mancuso et al 2021).

Therefore, it is an advantage for farmers to know the nutrient content of their slurry before application. If nutrients in slurry can be better utilised for agronomic growth, economic costs can be reduced by saving on artificial fertiliser use, and slurry runoff leading to nutrient leaching into waterways can also be reduced (Piccinini and Bortone, 1991) while also providing a solution to animal waste disposal (Holden *et al.* 2004).

This report aims to assess if dairy farmers in the Mournebeg catchment area of Castlederg Co. Tyrone apply the appropriate slurry for grasses being cut for silage.

This will be met through the following objectives:

- Using a gravity slurry hydrometer to obtain N, P and K values in kg/m^3.
- Asking farmers about their current slurry application rate and why they apply this amount.
- Calculating the N, P and K amount spread per hectare (ha) by each farm from the dry matter content obtained from the gravity hydrometer, using the application rates provided.
- Comparing N, P and K values applied per ha on each farm with the DAERA nutrient spreading guidelines and limits using the DAERA Nutrient Action Plan.

Finally, 'Are dairy farmers in the Mournebeg catchment area utilising their slurry efficiently as a fertiliser source for grass and silage production?' will be answered, and recommendations will be made accordingly.

2. Methodology

2.1 Study Area

The focus area is in West Tyrone, Northern Ireland, in the Mournebeg catchment area of Castlederg. The Mournebeg River joins the river Derg which collectively supplies water to the local area of 30,000 people (Morton *et al.* 2021). Figure 1 below shows the locations of the four dairy farms used in this study, with all dairy farms having a Holstein dairy herd. Manure is scraped to an underground storage tank during the housed winter period on all farms. Slurry is spread on the four farms on land used to produce silage twice a year.

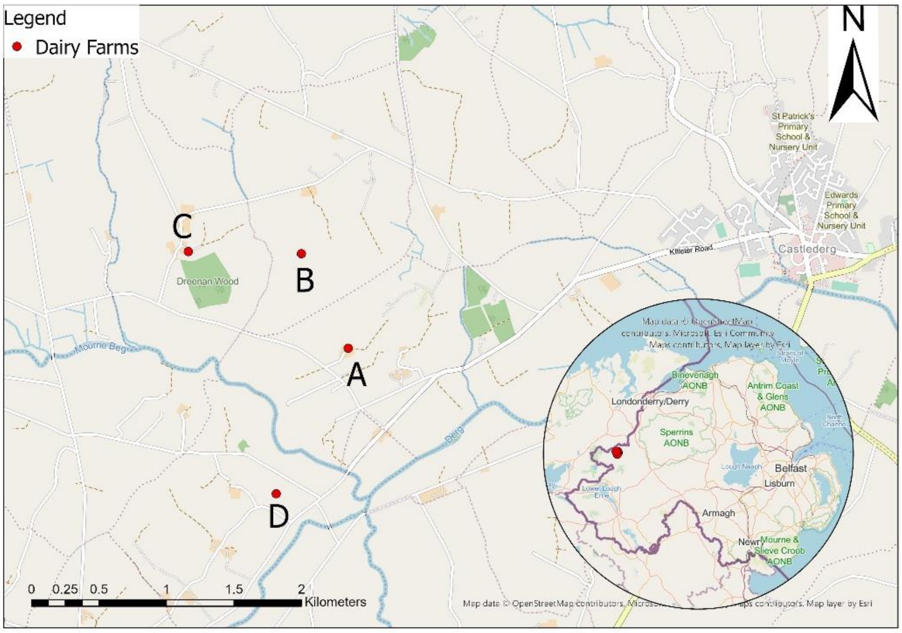

Figure 1: A map of the study locations in the Mournebeg catchment area of Castlederg, Co. Tyrone. Each farm is labelled.

2.2 Hydrometer sampling method

During the summer of 2021, two well agitated slurry samples were collected in a 30cm deep bucket from each of the four dairy farms in the study. The samples collected by the farmers after the slurry was agitated by mixing the slurry tank. One sample was collected after the first cut of silage and another after the second cut of silage.

A glass gravity hydrometer (Figure 2a) was used to measure the dry matter percentage of the slurry, by being placed into the 30cm deep bucket. The hydrometer was allowed to sink and once settled, the dry matter reading was taken by reading the value closest to the slurry surface (Figure 2b).

This method was repeated three times for each sample (with the hydrometer being rinsed clean and dried after every measurement) and an average was taken.

The depth of the bucket had to be greater than the hydrometer itself to allow the hydrometer to sink (Salazar and Rosas, 2012). Research has shown a statistically significant correlation between dry matter and fertiliser elements in cow manure (Piccinini and Bortone 1991). A density measurement using a hydrometer finds the dry matter content of the slurry, which can then be converted to fertiliser elements content to find N, P and K values (Piccinini and Bortone 1991; Singh and Bicudo 2005). Freshly agitated slurry was required due to the non-homogenous nature of slurry (Zhu *et al.* 2004). Therefore, the hydrometer test was conducted on the samples within one hour after mixing to ensure the solids in the manure did not settle (Zhu *et al.* 2004).

Figure 2(a): The glass slurry gravity hydrometer used in this study is 25cm long.

Figure 2(b): The gravity hydrometer settled in the dairy slurry sample. The measurement of 7 was

Lab-based analysis was avoided in this study as it is not cost-effective and requires a longer time to receive results back from laboratories, proving impractical for most farms (Piccinini and Bortone, 1991; Kessel and Reeves, 2000; Provolo and Martínez-Suller, 2007). When the test results are returned, slurry application to fields has already begun (Singh and Bicudo 2005). This means that there is a risk of over or under application of slurry to fields, as results will not be known until the following year (Singh and Bicudo, 2005).

‘Quick tests’ are quick to perform and obtain results, which can be received before slurry is applied to fields (Singh and Bicudo, 2005). Some examples of quick tests include the Agros Nova Meter, the electric conductivity meter, and a gravity hydrometer (Kessel and Reeves, 2000).

The gravity hydrometer quick method was used for this study as it is an easy piece of equipment to use (Zhu *et al.* 2004) and can be used by farmers practically on the farm. It is inexpensive, portable and takes less than ten minutes to complete (Singh and Bicudo 2005). The hydrometer also stands out from other quick methods due to its accuracy and ease of use for farmers (Singh and Bicudo, 2005; Salazar and Rosas, 2012). Slurry management can therefore be improved on farms.

This made the gravity hydrometer a suitable piece of equipment for this study to obtain the dry matter content of slurry. This method can be easily replicated by farmers in the future, meaning nutrient values of slurry will be known before slurry application to fields. Accessible methods to quantify the nutrient values of the slurry are needed to encourage farmers to use it as an efficient nutrient source and reduce pollution risks (Scotford *et al.* 1998).

2.3 Nutrient application rates (kg/ha)

Once the dry matter content of the slurry was found it was then converted to N, P and K values in kg/m^3 using figure 3 below provided by Teagasc. Previous research by Piccinini and Bartone (1991) and Salazar and Rosas (2012) found that the dry matter content of slurry positively correlates with N content.

During slurry sample collection, each farmer was asked their current slurry application rate, which was given in gallons per acre, and was then converted to kg per hectare (kg/ha). Each farmer was also asked if they spread any additional fertiliser to fields used for silage production (e.g., artificial fertiliser) and, if so, how much. The answer was often given in percentages and units, which was also converted to kg/ha. The total slurry spread by each farmer was compared to the current DAERA slurry spreading limit of 50m^3/ha, which is limit used after February, as this is when farmers were applying slurry to fertilise grass for silage. Any additional fertiliser used was then added, and recommendations were made accordingly.

		kg/m^3			kg/1000 gals			units/1000 gals		
Slurry	**Dry Matter %**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Cattle	**1**	0.2	0.1	1.0	0.9	0.6	4.5	2	1	9
	2	0.4	0.2	1.4	1.6	1.0	6.4	3	2	13
	3	0.5	0.3	1.9	2.4	1.3	8.6	5	3	17
	4	0.6	0.4	2.3	2.9	1.7	10.4	6	3	21
	5	0.8	0.5	2.7	3.6	2.0	12.3	7	4	25
	6	1.0	0.5	3.2	4.4	2.4	14.5	9	5	29
	7	1.1	0.6	3.6	4.9	2.8	16.3	10	6	33
	8	1.2	0.7	4.0	5.6	3.1	18.2	11	6	36
	9	1.4	0.8	4.4	6.2	3.5	20.0	12	7	40
	10	1.5	0.8	4.9	6.9	3.8	22.2	14	8	45
Pig	**2**	1.5	0.4	1.7	6.8	2	7.5	14	4	15
	4	2.0	0.9	2.1	9.1	4	9.4	18	8	19
	6	2.5	1.3	2.5	11.4	5.9	11.3	23	12	23

Figure 3: Slurry Hydrometer Conversion Table for available N, P and K content (Teagasc, 2015).

Farmers were asked if they are aware or have previously tested the phosphorus levels of their soil. This was done as soils with a high phosphorus level require little to no additional phosphorus, therefore, slurry recommendations will vary.

Finally, the slurry and nutrient application amounts per hectare (ha) were compared to DAERA limits and guidelines. Recommendations were made based on the slurries dry matter content, nutrient application per ha and, if known, the soil P level on the farms. Recommendations were made that ensured farmers were utilising the most efficient amount of nutrients from their dairy as an agronomic asset, so artificial fertilisers costs can be reduces, while also not overapplying nutrients that may cause harm to the aquatic and atmospheric environment.

3. Results

3.1 Dry matter content

The first slurry samples from the study farmers were collected from the 6th May 2021 to the 16th of May 2021, just before the slurry was applied to fields after the first cut of silage when farmers were mixing slurry tanks. The second sample was collected between 1st July 2021 and 14th July 2021, when slurry tanks were mixed before the second slurry application.

Dry matter content varied between a) the two samples taken from the same farm and b) the four dairy farms in the study (Table 1). The dry matter content of the slurries never fell below 2% or exceeded 8%. Farm B had the largest variations in dry matter content, having both the highest and lowest dry matter content results recorded in the study.

Table 1: Gravity hydrometer reading results for each farm and the date each sample was taken and tested. Hydrometer reading was converted to N, P and K values in kg/m^3, and slurry spreading rate can be seen in m^3/ha.

Sample Set	Farm	Date Sampled	Hydrometer Reading	Element	kg/m^3	Slurry spreading rate (m^3/ha)
1	**A**	06/05/2021	7	N	1.1	22.47
				P	0.6	
				K	3.6	
	B	08/05/2021	8	N	1.2	28.08
				P	0.7	
				K	4	
	C	12/05/2021	4	N	0.6	22.47
				P	0.4	
				K	2.3	
	D	16/05/2021	8	N	1.2	28.08
				P	0.7	
				K	4	
2	**A**	06/07/2021	8	N	1.2	16.85
				P	0.7	
				K	4	
	B	17/07/2021	2	N	0.4	28.08
				P	0.2	
				K	1.4	
	C	01/07/2021	6	N	1	22.47
				P	0.5	
				K	3.2	
	D	14/07/2021	7	N	1.1	28.08
				P	0.6	
				K	3.6	

Farm A and C dry matter content increased from the first sample to the second while farm B and D dry matter content decreased. In the first set of samples taken just before application after silage was cut for the first time that year, dry matter content ranged from 4% to 8%. The second set of samples' dry matter percent ranged from 2% to 8%.

Using Figure 3, the hydrometer reading of each slurry sample was converted to the N, P and K amounts in kg/m^3, which can be seen in Table 1 above. A higher dry matter content equates to a larger N, P and K value.

On collecting the eight slurry samples, the farmers were asked how much of this slurry would be spread per hectare (ha), which can be seen in Table 1 above. The most common response was 28.08m^3/ha, with farms B and D applying this amount on the first and second applications (Table 1). Farm C applies 22.47m^3/ha of slurry on the first and second applications. Farm A also applies this amount during the first application, decreasing to 16.85m^3/ha on the second application. When asked the reason for this, the farmer responded that they are aware of DAERA limitations on nutrient application and do not want to exceed this amount, as additional fertiliser is also applied.

3.2 N, P and K amounts (kg/ha) applied with current application rates

Using the N, P and K values in kg/m^3 and spreading rates from table 1, calculations were made to determine the N, P, and K amount applied by slurry per ha at each farm at each spreading period (Table 2).

From table 2, farm D applies the highest amount of nutrients from their slurry (64.59 kg/ha of N), while farm C applies the lowest nutrient amount from their slurry (39.95kg/ha of N). Farm A and B apply to the same nutrient amount per ha (44.93kg/ha of N) as although farm A's slurry contains an overall higher nutrient content, farm B applies a larger amount of slurry per ha.

On sample collection, farmers were also asked if they spread any additional fertiliser in addition to the dairy slurry to produce silage, so that total nutrient application could be calculated for silage producing fields. Farm A and B both spread pig slurry on their silage fields, which comes from farm B's pig unit. Farm A spreads 22.47m^3 of pig slurry after the first and second cut of silage, while Farm B spreads 22.47m^3 after the second cut of silage. In addition to the dairy slurry, farm C spreads 202kg of 25% N artificial fertiliser per hectare annually, which converts to 99.96 kg N/ha. This means 49.97kg of N/ha is applied per application. Farm D spreads 87.5kg N/ha of artificial N per silage cut. This means that a total of 175kg N/ha is applied annually.

Using this information and the spreading rates provided by farmers (Table 1), the total nutrient values applied by farmers each year to silage producing fields by dairy slurry and other additional fertilisers were calculated, and this information can be seen below in Table 2.

Overall, farm D applies the highest nutrient content per ha than the other three farms in the study, applying 239.59kg/ha of N per application (Table 2).

As seen in Table 2 below, a higher dry matter content (%) of slurry equates to a higher nutrient content available in the slurry. Therefore, spreading a larger volume of slurry containing a high nutrient content means that the slurry is being utilised more effectively as a fertiliser.

Table 2: Nutrient value (N, P and K) applied per hectare at each farm in kg/ha.

(* = pig slurry. The typical dry matter content of pig slurry of 4% was taken from Nutrient Management Guide (RB209) p.11)

Farm	**Dairy Slurry application (m^3)**		**Nutrient**	**1st slurry application**	**2nd slurry application**	**Total nutrient content applied from slurry**	**Additional fertiliser applied annually**	**Total nutrient application per year**
	1st application	2nd application		(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
A	22.47	16.85	N	24.71	20.22	44.93	*89.84	134.77
			P	13.48	11.80	25.28	*40.44	65.72
			K	80.88	67.40	148.28	*94.38	242.66
B	28.08	28.08	N	33.70	11.23	44.93	*44.94	89.87
			P	19.66	5.62	25.28	*20.22	45.50
			K	112.32	39.31	151.63	*47.19	198.82
C	22.47	22.47	N	13.48	22.47	35.95	99.96	135.91
			P	8.99	11.24	20.23	10.12	30.35
			K	51.68	71.90	123.58	0.00	123.58
D	28.08	28.08	N	33.70	30.89	64.59	175.00	239.59
			P	19.66	16.85	36.51	0.00	36.51
			K	112.32	101.09	213.41	0.00	213.41

3.3 Possible spreading rates with nutrient amounts applied

The organic slurry spreading limit in Northern Ireland set by DAERA per application after February is $50m^3$/ha, while soils with an Olsen P index above 2 should have an application of $33m^3$/ha.

At the end of the study, each of the four farmers were asked if they had recently tested their soil for available P. Farmers A and B stated that they tested their soil in 2020, having an Olsen-P index of 4, while Farmers C and D stated they had not tested their soil.

The spreading rates mentioned above were applied to each slurry sample, and these results can be seen below in Table 3.

From Table 3, if farmers spread the maximum amount of $50m^3$/ha of slurry, N amounts applied per ha would almost double in amount, meaning a higher amount of nutrients could be utilised from slurry while still being under the annual maximum limit of 170 kg N/ha for organic manure. As seen in table 3, farms, A and D have the prospect of applying the highest nutrient content per hectare, with farm C applying the least due to the lower dry matter content of their slurry.

Table 3: The N, P and K amount available at $50m^3$/ha application rate and $33m^3$/ha application rate, given in kg/ha.

Sample Set	**Farm**	**Element**	**Application rate of $50m^3$/ha** (kg/ha)	**Application rate of $33m^3$/ha** (kg/ha)
1	**A**	N	55	36.30
		P	30	19.80
		K	130	118.80
	B	N	60	39.60
		P	35	23.10
		K	200	132.00
	C	N	30	19.80
		P	20	13.20
		K	115	75.90
	D	N	60	39.60
		P	35	23.10
		K	200	132.00
2	**A**	N	60	39.60
		P	35	23.10
		K	200	132.00
	B	N	20	13.20
		P	10	6.60
		K	70	46.20
	C	N	50	33.00
		P	25	16.50
		K	160	105.60
	D	N	55	36.30
		P	30	19.80
		K	180	118.80

4. Discussion

Overall, it can be seen from the results section above that each farm has very different nutrient values contained in their slurry with very different soil nutrient needs. Therefore, each farm will be looked at individually.

Farm A

Farm A’s first slurry sample had a lower dry matter content than the second sample (Table 1); however, both samples are high in nutrients, with 7% and 8%.

On collection of the slurry samples, Farmer A said that their most recent soil P value was taken in 2020 and was an index of 4 on the Olsen test. This means that there is a very high level of P available in the soil and that additional P will not give a more significant yield in grass crop production (Teagasc 2020). Using this information, the soils used for silage production cannot hold an excessive additional amount of P and there is sufficient P already available in the soil for grass production. According to annexe J of DAERA's NAP in 2019, soil with a P index of 4 requires no additional P applied to soils to produce silage. However, farmers spreading their own slurry can exceed these recommendations. In an article posted in April 2020(c), DAERA recommended that soils with an Olsen P index of above 2 should not spread higher than 33m^3/ha of dairy slurry. Therefore, if farm A increases their dairy application to 33m^3/ha rate, they could increase the amount of N applied per ha by 24.08kg N/ha annually. As seen in Table 3, a higher N value will be applied than current, meaning the slurry as a resource is utilised more efficiently, while not causing environmental harm from overapplication.

According to Teagasc's 'major and micronutrient advice for productive agricultural crops’ (2020), grass being produced for the silage requires at least 100kg N/ha (Teagasc 2020). More N requirements for silage crops will be covered if farmer A increases their spreading rate.

However, farm A's additional application of pig slurry also needs to be considered. As the pig slurry used by farm A was not tested using the hydrometer, typical dry matter content according to (AHDB 2021) Nutrient Management Guide of pig slurry will be used along with Figure 3. Pig slurry's typical dry matter percentage is 4% (AHDB 2021). Using the current spreading rate given by farmer A, a higher nitrogen content is available in the pig slurry over the dairy (Table 2). Therefore, farm A may consider only applying pig slurry to grazing fields as suggested by (Teagasc n.d.). Pig slurry application could also be decreased to under 20m^3/ha, as this would still be below the maximum spreading limit of 50m^3 and would also be below the recommended P limits of 41kg P/ha for soil indices above 2.

As stated by Amon *et al.* (2006), slurries with a higher dry matter content applied to fields release a larger amount of NH^3 emissions. Therefore, a lower amount of the high dry matter content slurry should be applied to reduce emissions. This leads to the problem of having an excess of dairy slurry that is not needed for crop growth, which will be discussed later.

Farm B

Farm B is currently spreading 28.08 m^3/ha of dairy cattle slurry per application, which equates to 44.93kg of N/ha applied annually from their dairy slurry (Table 2).

Farm B's dry matter content drops from 8% to 2% from the 1st sample to the 2nd sample (Table 1), meaning the slurry is getting more dilute, which could be due to excess parlour washings entering the underground slurry tank (Teagasc 2022). This means that farm B's total nitrogen output onto soils from their dairy slurry decreases from 33.65kg/ha to 11.23kg/ha using their current slurry application rates, meaning farm B is underutilising their slurry and under fertilising their silage crops.

Farm B's Olsen-P test result was an index of 4 in 2020. This again means that soils on farm B have sufficient P levels, so the DAERA recommended 33m^3/ha and an N limit of 34kg N / ha is recommended on these soils (DAERA 2020c). Farm B's second slurry sample has a much lower dry matter content than the first sample. If applying 33m^3/ha of slurry sample two, only 13.2kg of N will be spread per ha (Table 3). To utilise the nutrients contained in this slurry sample more efficiently, it is recommended that the maximum slurry spreading limit of 50m^3/ha is used for slurry sample two, as this would enable 20kg N/ha and 10kg P/ha to be applied on application (Table 3), which is below the guidelines set by DAERA. Although the dry matter content of farm B's second slurry sample does contain fewer nutrients, due to the lower dry matter content, this slurry has a better chance of infiltrating through the soil at a quicker rate, therefore decreasing the time spent exposed on the surface, which will decrease NH^3 levels released (Carozzi *et al.* 2013).

The additional pig slurry spread by farm B also needs to be considered. Farm B's current slurry spreading rate means 50.55 m^3/ha is applied during the second application, which is over the maximum slurry spreading guidelines set by DAERA at 50m^3.

If farm B wishes to continue to spread 22.47m^3/ha of pig slurry in conjunction with the dairy slurry during second application date, the maximum application rate of dairy slurry would be 27.53m^3/ha. This would mean 25.73kg P/ha would be applied at the second application. This is below the DAERA recommendation of 41kg P/ha of soils with high P indices and a higher current N value of 55.95kg N/ha, meaning a higher amount of N is utilised from Farm B's slurry.

Farm C

Farm C is spreading under the DAERA guidelines at 22.47m^3/ha after the first and second cut of silage (Table 2). A total of 35.95kg of N per ha is spread per year. Currently, farm C is also applying 49.97kg of artificial N/ha, meaning the total N amounts spread annually from slurry and fertilisers is 135kg of N per ha (Table 2). Dairy farms' chemical N fertiliser limit is 272kg/ha per year (DAERA 2019). Teagasc recommends that grass produced for silage requires at least 100kg of N per ha (Teagasc 2020). Therefore, using Table 3, if farm C increased application rates to the maximum 50m^3/ha, they could utilise more nutrients available in their slurry to increase agronomic growth.

Farm C has not tested their soil for P levels, so it is unknown what P amount is already available in their soils. Therefore, applying a higher slurry rate for silage production risks the overapplication of phosphorus, which risks excess P runoff or leaching into watercourses. If farm C had a soil P-value above index 2, the recommended application rate according to DAERA would be 33m^3/ha, as shown in table 3.

With the lower dry matter content, the slurry will also infiltrate through the soil at a quicker rate which will also decrease NH^3 amounts being lost (Ryan 2005; Carozzi *et al.* 2013).

Farm D

Farm D dry matter content of slurry remains high between the first and second sample (Table 1). This means that they are gaining the maximum nutrient content from using slurry as a fertiliser.

Farm D is spreading 28.06 m^3/ha per application of dairy cattle slurry, utilising 64.57 kg/ha N per year (Table 2). If farm D increases slurry spreading to 50m^3/ha per application, they will utilise 116.16 kg/ha of N a year (Table 3), cutting down on artificial fertiliser use and its associated costs.

Using the Teagasc (2020) recommendations of silage crops needing 100kg N/ha, farm D would need an additional 40kg N/ha when applying slurry sample 1, reducing fertiliser use by 47.5kg N/ha. If the same principle is applied to the second slurry sample, 45kg of chemical N would be needed to meet crop requirements, meaning a reduction of 42.5kg N/ha. Annually, this is a total reduction of 90kg N/ha, meaning both a reduction of costs for farmers and a reduction of available N that can be leached from soils, as all the N is being assimilated by the grass crop (Price *et al.* 2011).

However, as farm D is not aware of the P availability of their soil, there is a risk of over-applying P. Therefore, it is recommended that farm D test their soil and apply a larger rate of slurry on fields with a low P-value and a lower application of slurry on high P soils.

Overall, all four dairy farmers in the Mournebeg catchment area are underutilising their slurry efficiently as a fertiliser source for grass and silage production as they are unaware of the nutrient content available in their slurry, and they are applying below the maximum slurry application limit set by DAERA.

Each farm has different slurry nutrient contents and available soil nutrients; therefore, a general increase in slurry application cannot be generally made.

Teagasc (2020) recommends that a higher slurry application containing a high level of nutrients be confined to areas where the risk of surface flow is small (non-sloping areas) and the risk of P loss to water is minimal. DAERA guidelines state that slurry may not be spread closer than 10m from a waterway. Therefore, the general recommendation from this paper would be to spread a reduced amount of the high dry matter content slurry if spreading in the risk areas mentioned above.

'Typical' dry matter content of dairy cattle slurry in the Nutrient Management Guide (RB209) was 6% (AHDB 2021), while the dry matter content in this study varied from 2-8%. Therefore, it is recommended that farmers test the dry matter for their slurry as it is variable and can be influenced by factors from farm to farm like diets, dirty water volume and the amount of bedding used (AHDB 2021).

A limitation of the study was that the dry matter content (%) of the pig slurry used by both farms A and B was not tested. If the study was repeated, the hydrometer method would be completed on this pig slurry to gain a more accurate result on the total nutrients spread at both farms.

To further expand on this study, more knowledge of each dairy herd's diet would mean a better understanding of the variations in dry matter content between the two slurry samples. It is understood that the nutrient content of manure can be affected by the nutrition and diet of the animal (Kessel and Reeves, 2000) and reducing the P content of a cow's diet can reduce P outputs in faeces and improve P use efficiency (McConnell *et al.* 2016). A further look into each dairy farm's cattle diet and how the cattle's diet changes throughout the year may offer a better understanding of how the dry matter content of slurry can be manipulated to become a source of nutrients for crops.

For this study, only slurry application to fields used for silage production was studied; however, if repeating this study, grazing fields could also have been included and studied, and comparisons could have been made.

Without the knowledge of each farm's soil P content, the amount of P available in the soil is unknown, and therefore the amount of P that is necessary to apply to soils is not known. This, therefore, increases the risk of overapplying P to soils. The current DAERA recommendation on soil testing is that it is only required if farms wish to apply any additional chemical P (DAERA n.d.), which doesn't apply to the farms in this study. Farm A and B test their soils every four years with the last test being completed in 2020 and having an overall value of 4. To improve this study, soil analysis would be completed on all four dairy farms.

As mentioned above, farm B is currently applying over the maximum limit of slurry to silage grasslands due to the excess manure produced on their farm by cattle and pigs. This could be solved by 'manure transferring', where farms that produce an excess of manure can be linked to a less insensitive farm (e.g. sheep) (Cassidy *et al.* 2019). Less intensive farmers would benefit from this, especially as the prices of artificial fertilisers have increased (FarmingUK, 2021). This transfer may be challenging in terms of costs and fears surrounding biosecurity. However, if transferring to local farms, there may be a higher level of trust (Cassidy *et al.* 2019). A similar manure management programme is currently being implemented in the Chesapeake Bay catchment area in the United States, as stated by Kleinman *et al.* (2012), where manure and slurry are redistributed from areas in surplus to areas in deficit. This could be achieved on a small scale with the local farmers in the Mournebeg catchment area, which then has the possibility of expanding to the surrounding Derg catchment area and beyond.

This could then be developed further by testing the soils of all farmlands in the catchment and creating a detailed catchment soil P map, as previously done by Shore *et al.* (2014). Slurry produced with a high dry matter content with associated high level of nutrients can be matched to soils with a low P content (Teagasc 2020), enabling higher agronomic utilisation of nutrients from slurries. Large amounts of P being applied to soils with an already high P-value would increase the risk of P leaching into waterways (Cassidy *et al.* 2019), and the use of slurry on cropland must be suited to each soil's characteristics to reduce excess nutrient runoff and pollution (Provolo and Martínez-Suller 2007).

While nutrient management is essential for reducing diffuse and atmospheric pollution from slurry, (Gibbons *et al.* 2014) found that local eutrophication events in their study of sustainable nutrient management were linked to be more likely attributed from improper nutrient application and timing rather than from overapplication of nutrients. For best management practice and to reduce atmospheric losses, farmers in this study could switch to direct injection instead of surface slurry spreading, as in a study carried out by (Carozzi *et al.* 2013), direct injection reduced NH^3 losses from slurry by 95% compared to surface spreading.

Using the gravity hydrometer to measure dry matter slurry worked well in this study as it was simple to use and results were instant, which was also found by Singh and Bicudo (2005). The conversion from dry matter content to nutrient elements in the slurry was also straightforward. However, it was difficult to get accurate measurement due to the analogue scale. It has also previously been seen by Scotford *et al.* (1998) that without the complete mixing of slurry in the tankers, the hydrometer readings may not represent the total nutrient status due to the random sample not representing the relative amounts of settled and unsettled material. Therefore, if the experiment was repeated, it may be beneficial to include lab analysis to validate the results further.

5. Conclusion

Prior to hydrometer readings being taken, the initial assumption was that farmers did not spread the correct amount of slurry required or needed for their land to produce grass for silage due to being unaware of the nutrient content of their slurry. From the results and discussion above, this was proven to be correct. The main findings of the study are as follows:

- All farmers are currently underutilising their dairy slurry as a nitrogen fertiliser source.
- The dairy farmers in this study are applying slurry at a rate under the DAERA limits.
- The four farmers are unaware of the nutrient content available in their dairy slurry available for crop production.

Overall, it can be concluded that slurry with a high dry matter content which contains a higher nutrient content should be spread on areas with a low soil P level and areas that are not at risk of leaching nutrients. In contrast, a higher volume of low dry matter slurry should be applied. In areas with a high soil P index, slurry with a high dry matter content should be made at a lower application and slurry with a lower dry matter content can be applied at higher rates.

The hydrometer proved an efficient method for calculating the N, P and K amount in each slurry sample by defining the dry matter content. It is a piece of equipment that farmers can use each year before applying slurry to land.

When asked why they applied their current slurry volumes, all replied that it was to empty their slurry storage tanks, suggesting slurry is primarily used as a waste disposal solution.

To further expand on this study, it would be recommended that all farmers test their soils to obtain the P-value content of their soils. Farmers would then know how much P is already available in their soil and how much additional P from slurry fertiliser would be needed for crop fertility. Overapplication of P would then be avoided, which would reduce the risk of P runoff into waterways, further reducing the risk of water quality degradation.

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