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Economic evaluation of a range of options for the management of soiled water/dilute slurry on Irish dairy farms

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ABSTRACT
Dairy soiled water (DSW) is water collected from concreted areas, hard stand areas and holding areas for livestock that has become contaminated by livestock faeces or urine, and parlour washings and must be managed in compliance to the Nitrates Directive S.I.610.2010. The objectives of this study were to evaluate the economic outcomes from a range of options for the management of DSW on Irish grass based dairy production systems. The management options evaluated were DSW stored separately for 10 days, DSW recycled using a woodchip and a sand filter, and DSW mixed together with slurry. The different options investigated centred around contrasting methods of DSW storage and application. The overall mean net costs for storage, treatment and application were €242, €1536 and €849 respectively[4]. The mean savings were €15 per cow across management options, consisting of savings from fertiliser, water, increased herbage DM production. The management option of storing DSW with slurry had higher savings compared to MO1 and MO2, which were attained from extending the grazing season length, using low cost storage and application methods combined with strategic application during the growing season for optimum NFRV and DM response.

KEYWORDS: dairy soiled water; dilute slurry management; woodchip filter

1. Introduction

Worldwide demand for dairy products is expected to rise as a result of global population growth and projected increases in per capita disposable income (Donnellan *et al.*, 2011). In the Republic of Ireland, dairy output represents 30% of all Irish agri-food exports (Department of Agriculture, Food and Fisheries, 2012 a). Dairy production in Ireland is characterised by a seasonal spring calving system with the objective of high utilisation of grazed grass in the diet (Dillon *et al.*, 2008) and these systems have economic (Shalloo *et al.*, 2004) and environmental advantages (Ryan *et al.*, 2012). In Ireland and Europe, the dairy industry is currently experiencing a period of change, with the impending removal of milk quotas in 2015. In the Republic of Ireland this change will result in increased pressure for dairy systems to maximise the economic returns, in the context of a milk price that is more volatile, as the interaction between dairy product supply and demand interact (Donnellan *et al.*, 2011). Increasing overall dairy cow numbers facilitated by increasing stocking rates should be focused on increased grass utilisation which will increase the overall dairy enterprise profitability (Shalloo *et al.*, 2007). This increase in cow numbers on farms will lead to the production of greater volumes of dairy soiled water (DSW), which will require effective environmental and economically sustainable management options. Within the European Union, there has been increasing regulatory pressure to lower losses of nitrogen (N) to water and to the environment, through national regulations stemming from the Nitrates Directive and Water framework Directive (Council of the European Communities, 1991).

Dairy soiled water is water collected from concreted areas, hard stand areas and holding areas for livestock that has become contaminated by livestock faeces or urine, and parlour washings and must be managed in compliance to the Nitrates Directive (Minogue *et al.*, 2010). Dairy soiled water contains valuable but variable levels of nutrients such as N and phosphorus (P) (Minogue *et al.*, 2010). Soiled water is legally defined in Ireland as having a five day biochemical oxygen demand (BOD) of $<$2,500 mg L^{-1}, $<$1% dry matter (DM), has a minimum storage requirement of 10 days and can be applied all year round based on the Nitrates Directive requirements (SI No.610, 2010). Minogue *et al.*, (2010), investigated DSW on Irish dairy farms and found that 73% and 87% of samples complied with the legal definition of soiled water based on the BOD (mean

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[4] In mid-December 2013, €1 was approximately equivalent to $1.38 and £0.84 (www.xe.com)

Table 1: Description of spring calving dairy system

Dairy System Description	
Average number of cows	80
Mean calving date	17 February
Mean dry off date	18 December
Milk yield per cow (kg/cow)	5356
Milk fat%	4.38
Milk protein%	3.56
Milk solids yield (kg MS/cow)	414
Stocking rate (LU/ha)	2
Grazed grass intake (kg DM/cow)	3110
Silage intake (kg DM/cow)	1333
Concentrate intake (kg DM/cow)	408
Culling%	17.8
Average Live weight (kg/cow)	535

2246 mg l^{-1}) and DM (mean DM 0.5%) content respectively.

In the Republic of Ireland all farmers are obliged to observe the requirements of the Nitrates Directive including those for minimum slurry storage capacity. Where livestock excreta and soiled water are mixed in a collecting yard tank or slurry tank, this material is characterised as slurry and cannot be spread during the closed period (SI 610, 2010). Alternative management strategies such as the use of aerobic woodchip filter (Ruane *et al.*, 2011) and sand filter (WSF) (Ruane *et al.*, 2012) to remove organic matter, suspended solids (SS) and nutrients from DSW, would allow the re-use of the filtered effluent to wash down yards. This would reduce the total water usage and environmental risks associated with land spreading. The use of such a bio-filtration system creates a synergistic opportunity from both an economic and environmental perspective to reduce costs associated with water use and also to maximise the potential from nutrients in the slurry.

The objectives of this study were to evaluate the economic outcomes from a range of options for the management of soiled water/dilute slurry on Irish grass based dairy production systems. The management options investigated the economic effect of contrasting storage and application methods, combined with a range of storage periods. The effect of application timing, agronomic response, and fertiliser replacement value were included in the analysis. The investigation combined the production and economic interactions and consequences of DSW management options, based on alternating grazing season lengths in grass based seasonal calving dairy production systems. The options investigated were; storing DSW for a minimum of 10 day's (MO1), recycling DSW using a WSF (MO2), and storing DSW in the existing on farm winter slurry storage facilities (MO3). The different options investigated centred around contrasting methods of DSW storage, treatment and application, to assess the most economic and environmentally viable management option for DSW.

2. Materials and Methods

Dairy Soiled Water (DSW) model description

The DSW model described in this paper is a simulation model developed to assess the economic consequences of different management practices relating to DSW management practices in pasture based seasonal calving dairy production systems. The different DSW management practices investigated in the model include; DSW storage method, storage period, DSW application method, application timing, DSW filtration and water recycling. The management practices were evaluated to assess the effect on costs, savings, and farm profitability. The different management options were investigated under different scenarios described below.

Dairy production system physical performance

The physical profile of the dairy system simulated was obtained from 3 years of research data (Ryan *et al.*, 2012) conducted at Dairygold Research Farm, at Moorepark, Animal and Grassland Research and Innovation Centre, Fermoy, Co Cork. Farm system production data were generated by the MDSM (Shalloo *et al.*, 2004) based on the system's physical performance profile (Ryan *et al.*, 2012) to simulate a grass based dairy production system with a mean calving date of 17^{th} of February and a mean lactation length of over 300 days. The dairy systems simulated were the same for all options investigated (Table 1).

DSW model description: Dairy soiled water nutrient value

Dairy soiled water is produced on Irish dairy farms through the washing-down of milking parlours and holding areas. It contains nutrients and other constituents that provide potential in relation to reduced costs and increased profitability. The characteristics (volume and nutrient content) of DSW produced on Irish dairy farms used in the DSW model are based on the findings of Minogue *et al.*, (2010). Minogue *et al.*, (2010), noted on average, 9784 l of DSW are produced per cow year^{-1}, containing 0.5% DM, 587, 80, 568 and 2246 mg l^{-1} of N, P, K and BOD respectively.

DSW model description: DSW storage and application

In the economic assessment, a variety of waste water storage, treatment and application practices were investigated. The construction and maintenance/running costs associated with different forms of waste water storage were based on average costs (DAFF 2006, 2007;

Table 2: Average Fertiliser Nitrogen (N), Phosphorus (P), Potassium (K), tap water and grazed herbage DM costs

Item	Average value €/T
Calcium ammonium nitrate (CAN) 27.5%N	€330
Urea 46% nitrogen	€400
Super-phosphate (16% P)	€425
Muriate of potash 50% K	€450
Tap water	€3
Grazed herbage DM	€127

O'Sullivan, 2012; Ryan 2012). The different types of waste water storage investigated were, waste water stored in concrete tanks (CT), waste water stored in over-ground circular slurry/effluent store (ST) and waste water stored in a geomembrane-lined lagoon (LT). The specifications of the storage facilities were based on the S123, S122 and S126 for CT, ST and LT respectively (DAFF 2006). These are the standard types of waste water and slurry storage facilities used in Ireland (Hyde *et al.*, 2006). Costs were calculated based on the average construction, deprecated over the recommended lifetime of the structure (DAFF 2006, 2007; O'Sullivan, 2012; Ryan 2012). The average cost per m^3 of storage capacity used for constructing a CT, LT and LT were €80, €37 and €30 and the lifetime of the structures were estimated at 20 years (DAFF 2006, 2007; O'Sullivan, 2012; Ryan 2012).

The DSW application methods investigated in the economic analysis were, the use of a contractor using a vacuum tanker (TA), a contractor using a umbilical spreading system (UA) and an on farm waste water pump and irrigator system (IA). The average costs used for the different methods of application were based on O'Sullivan, (2012) and industry average estimates. The TA and UA application costs were €55 and €150 per hour with the application capacity of 45.4 m^3 and 136.3 m^3 per hour respectively. There was an additional cost associated with the use of the UA application method, due to the initial setting up and laying out pipes etc, there was a minimum charge of €750 (5 hours work). The IA costs associated with on-farm fixed irrigator pump and application system, were the initial installation cost of €8,000 for pump, piping and irrigator applicator, capable of pumping 4 m^3 per hour for 4 hours each day with an average electricity usage of 2200 KWH year with a running cost of €0.181 per KWH and the lifetime of the equipment was estimated at 8 years. In the management options investigated, the IA was only used for applying DSW with a DM$<$0.5% which is the typical practice undertaken in Irish farms for DSW.

DSW model description: DSW treatment and recycling

Data used to simulate the performance of a WSF using wood chip and sand filters were based on the findings of Ruane *et al.*, (2011) and Ruane *et al.*, (2012). Ruane *et al.*, (2011) observed a reduction in chemical oxygen demand (COD) of 66% and nutrient removal rates of 57% and 31% for total nitrogen (TN) and phosphorus (P) respectively using woodchip. Ruane *et al.*, (2012) used a sand filter to further treat DSW exiting the woodchip filter, to produce an effluent capable for the re-use in washing yards. The COD was reduced by 56% and nutrient removal rate were 57% and 74% for TN and P respectively. An UV sterilisation filter/pump were also used to treat the effluent exiting the WSF to reduce the bacterial content of the recycled waste water for re-use as wash water. Woodchip was included in the analysis at €20 per m^3 based on average industry costs with sand included at €15 per tonne and the lifetime of the woodchip and sand were estimated at 2 and 5 years respectively, (Ruane *et al.*, 2011). The average estimated cost of a UV filter pump capable of pumping 1000 m^3 $year^{-1}$ was €2000, with an electricity usage of 1100 KWH year and the lifetime of the equipment was estimated at 8 years.

DSW model description: DSW economic assessment

The economic feasibility of the different options is based on differences in costs and/or differences in output. The management options investigated the use of alternative management strategies which create a number of potential cost differences or opportunities for increased production. The differences in costs were based on differences in the quantity of fertiliser used, water and DSW storage requirements, storage methods, spreading, and when the nutrients in DSW were taken into account, differences in the quantity of purchased fertiliser. The economic consequences for the savings obtained were based on current industry average fertiliser values, purchased water costs and DSW storage costs (Table 2). The value for increased production was based on the extra economic performance from a grass based dairy production system when extra herbage DM is grown and utilised within the system (Shalloo *et al.*, 2007). The nitrogen fertiliser replacement values (NFRV) of the nutrients contained in the DSW were based on findings of Minogue *et al.*, (2011, and 2012) (Table 3). The NFRV for the DSW mixed with

Table 3: Dairy soiled water (DSW) average nitrogen fertiliser replacement value (NFRV) and herbage DM response for Nitrogen (N) applied in spring, summer, autumn and winter applications

Application time	DSW NFRV%	Kg DM response to kg N
Spring	70	20
Summer	100	23
Autumn	50	10
Winter	50	5

Table 4: Management option 3 (MO3), in Nitrate regulations zones A, B, C and C1 prohibited application period and storage capacity required

Option	Nitrates zone	Prohibited Application period	Storage Capacity Required
MO3a[1]	A	15 October to 12 January	16 Weeks
MO3b[2]	B	15 October to 15 January	18 Weeks
MO3c[3]	C	15 October to 31 January	20 Weeks
MO3c1[4]	C1	15 October to 31 January	22 Weeks

[1]Management option 3a (MO3a).
[2]Management option 3b (MO3b).
[3]Management option 3c1 (MO3c).
[4]Management option 3c1 (MO3c1).

slurry was 40% (S.I. 610 2010). The DM response from the N applied in the DSW was based on the findings of Morrison *et al*. (1980).

Management options (MO) investigated

There were six management options investigated;

Option 1 (MO1), Comparison of DSW storage and application methods
In option MO1, an economic comparison and assessment of the different methods of DSW storage and methods of application of DSW were investigated. In this option, DSW is stored separately using CT, ST, and LT for the S.I. 610 (2010). Soiled water was stored for a minimum amount of time of (10 days) and applied all year round by application method VA, UA and IA. The annual average NFRV of 80% for DSW is used based on the findings of Minogue *et al*., (2012).

Option 2 (MO2), Comparison of DSW storage and recycling of water
In option MO2, the use of a WSF filter/treatment allows 80% of the DSW to be recycled as wash water. In this option, the untreated DSW is stored, for the S.I. 610 (2010) soiled water minimum amount of time, filtered through a WSF and 80% is recycled as yard wash water. The remaining DSW is applied all year round using the TA, UA and IA methods of application. In this option the same assumptions and storage methods are used in MO1.

Option MO3a–MOc1 (MO3a, MO3b, MO3c, MO3c1)
The effect of extended grazing practices on dairy soiled water storage in the nitrate regulations zone A, B, C and C1, with adequate on farm slurry storage.

Option MO3a, MO3b, MO3c, and MO3c1 investigate the implications of the prohibited application periods in different zones of the nitrate regulations (S.I. 610 2010),

Table 5: The economic consequences of management options MO1 to MO3 for different strategies for DSW with contrasting storage periods and methods of application for a spring calving dairy herd with 80 cows

Item	MO1[1]	MO2[2]	MO3a[3]	MO3b[4]	MO3c[5]	MO3c1[6]
Storage period (Days)	10	10	64	64	93	93
Quantity of DSW to be stored (m^3)	21	21	133	133	193	193
Storage costs CT[7]	€83	€83	€367	€321	€758	€758
Storage costs ST[8]	€38	€38	€170	€149	€351	€351
Storage costs LT[9]	€31	€31	€137	€120	€285	€285
Application costs TA[10]	€767	€153	€767	€767	€767	€767
Application costs UA[11]	€750	€750	€750	€750	€750	€750
Application costs IA[12]	€1043	€1009	€1034*	€1034*	€1030*	€1030*
Treatment costs WSF[13]	-	€1768	-	-	-	-
Frtiliser Nitrogen savings	€308	€20	€267	€267	€263	€263
Fertiliser Phosphorus savings	€108	€5	€93	€93	€92	€92
Fertiliser Potassium savings	€259	-	€194	€194	€186	€186
Water savings	-	€1523	-	-	-	-
Dry matter savings	€454	€37	€583	€583	€597	€597
Average net saving or (Cost)	€225	(€640)	(€214)	(€188)	(€466)	(€466)

[1]Management option 1 (MO1).
[2]Management option 2 (MO2).
[3]Management option 3a (MO3a).
[4]Management option 3b (MO3b).
[5]Management option 3c (MO3c).
[6]Management option 3c (MO3c1).
[7]Concrete tanks (CT).
[8]Circular slurry/effluent store (ST).
[9]Geomembrane lined lagoon (LT).
[10]Vacuum tanker (TA).
[11]Umbilical spreading system (UA).
[12]Farm waste water pump and irrigator system (IA).
[13]Woodchip filter and sand filter (WSF).
*DSW which was not mixed with slurry was applied using the IA method.

Table 6: Sensitivity analysis 2 (SA2), Fertiliser Nitrogen (N), Phosphorus (P), Potassium (K) and grazed herbage DM price increase

Item	Average value €/T
Calcium ammonium nitrate (CAN) 27.5%N	€ 370
Urea 46%N	€ 450
Super-phosphate (16% P)	€ 450
Muriate of potash 50% K	€490
Grazed herbage DM	€140

zones A, B, C and C1 respectively (Table 4). In this option, DSW produced during the prohibited application period of the different nitrate regulations zones A, B, C and C1, is allowed to mix with slurry during the closed period. The DSW is stored together with slurry for the maximum amount of time as specified for the respective zone A - C1 using the different storage types CT, ST and LT (Table 4). In this option, the economic consequences of extending the grazing season in relation to the costs associated with DSW storage and application method were investigated for the different nitrate regulations zones A, B, C and C1. The grazing season is extended until 01 December for zones A, B, C and C1, option MO3a, MO3b, MO3c, and MO3c1 respectively. The spring turnout date for zones A and B is extended to 17 February in MO3a and MO3b and spring turnout date for zones C and C1 is extended to the 17 March (MO3c and MO3c1). In this option, the farm system has the correct amount of slurry storage capacity required for nitrate regulations zone A - C1, and DSW is only applied to land during the spring, summer and autumn to maximise the agronomic benefits of the nutrients in the DSW.

Sensitivity analysis (SA)

Sensitivity analysis 1 (SA1)

In sensitivity analysis SA1, the effect of increased purchase price of water from €3 to €5 per m^3, was investigated.

Sensitivity analysis 2 (SA2)

The economic effects of increased fertiliser prices and increased value of DM were assessed. The price of N, P, K and DM were increased by a mean to 12, 6, 9 and 10% respectively (Table 5).

Sensitivity analysis 3A and 3B (SA3a, SA3b)

Sensitivity analyses SA3a and SA3b were undertaken to assess the economic effects of contractor application efficiency. This involved adjusting the average TA application rate from 45.5 to 36.6 m^3 per hour for SA3a and 54.5 m^3 per hour in SA3b.

3. Results

Storage period and quantity of DSW stored

In all options (MO1 to MO3) dairy herd size and land area remained the same, the storage period required for DSW ranged from 10 days to 93 days depending on the management option, resulting in the amount of storage required for the DSW produced to increase from 21 m^3 to 193 m^3 (Table 5). Option MO1 and MO2 had the shortest storage period of 10 days and the smallest quantity of DSW storage of 21 m^3. In MO3a to MO3c1, storage period increased from 64 days to 93 days with the quantity of DSW storage increasing from 133 m^3 to 193 m^3 respectively (Table 6).

Storage costs

There was a large range of farm costs for the different methods of storage between options MO1 to MO3. Similarly as the quantity of DSW and storage period increased so too did the storage costs. In option MO1 and MO2, the total annual DSW storage costs for the farm were €83, €38 and €31 for CT, ST and LT respectively (Table 5). In MO3a to c1 the farm CT storage cost were €367, €321, €759 and €759 for MO3a, MO3b, MO3c, and MO3c1 respectively. The ST and LT storage cost were 54% and 63% less than the CT storage method for all options.

Application and Treatment costs

In options MO1 to MO3, the mean application costs for the different methods of application were €767 €750 and €1030 for TA, UA and IA respectively. The mean application costs per cow were €9.4, €9.6, €13.0 for the UB, TA and IA methods of application respectively.

Option MO2 had the lowest application costs of €153 using the TA method of application (Table 5). The low cost was due to the reduced quantity of DSW for application, as all DSW was filtered through a woodchip and sand filter. Using a WSF allowed 80% of the DSW to be recycled as wash water which reduced the quantity of DSW for application. The application costs for MO2 were €153, €750, €1008, for TA, UA and IA methods of application respectively. The treatment costs for using the WSF in MO2 were €1768. The total application costs for MO3a to MO3c1 were the same as MO1 using the TA and UA method of application. Using either combination of application method (TA+IA or UA+IA) for MO3, the application costs were increased by a mean of 95% for MO3a and MO3b and 99% MO3c and MO3c1 compared to only using the TA and UA method of application. The TA cost for applying the DSW mixed together with slurry produced during the closed periods was €161 for MO3a, and MO3b and €234 for MO3c and MO3c1 respectively. The IA cost for applying the DSW produced outside of the different zones closed periods was €1034 for MO3a, MO3b and €1030 for and MO3c and MO3c1 respectively (Table 5).

The UA application cost was 2% less than the TA method for applying all the DSW or DSW mixed together with slurry. However if the quantity to be applied was above the minimum quantity no surcharge would be incurred and the cost would be a further 7% less than the TA method. The IA method of application was the most expensive for all options.

Total costs

The average total costs for MO1 to MO3c1 were €1502, ranging from €904 to €2224 depending on the combination of storage application method and treatment used (Table 5).

Option MO1 and MO2 had the same storage costs, in MO2 the application costs using the TA method were approximately 80% less. However MO2 had the additional cost of the WSF, which was an additional 146% of total costs compared to MO1. Similarly in MO3a to MO3c1 total storage costs were higher than the other options investigated, due to the increased storage period. However in MO3, DSW was stored for the entire closed period utilising the on farm slurry storage and the total storage costs were reduced by 31%, 40%, 2% and 2% for MO3a, MO3b, MO3c and MO3c1 respectively compared to if separate storage had to be constructed. The results from the different management options investigated show that DSW storage cost had the biggest impact on the total costs, increasing the storage period and using a costly method of storage increased total costs. Application costs were similar across all management options investigated.

Total Savings

In each of the different options investigated there were potential savings (reduced expenditure) that could be achieved based on the different management options used for the DSW. The savings were in the form of fertiliser, water savings, and increased herbage DM production. In MO1 to MO3 the mean total savings for fertiliser were €482, ranging from €25 to €676, the fertiliser savings were comprised of savings made from N, P, and K (Table 5). As the storage period and management changed in MO3c and MO3c1 due to a later turnout date, the mean savings obtained from fertiliser reduced by approximately 2%. However there was a 2% increase in the savings obtained from extra DM in MO3c and MO3c1 compared to MO3c and MO3b. The mean total saving generated from extra DM produced for MO1 to MO3c1 was €475 ranging from lowest saving made of €37 for MO2 to the greatest saving made of €597 for MO3c to MO3c1 (Table 5). The average total savings for MO1–MO3 were €1211, ranging from €1129 to €1584. The greatest total saving of €1584 were made in MO2, as 80% of the DSW was recycled generating a saving of €1523 from the reduction in purchased water.

Net effect

When the total cost changes and savings associated with the different options investigated are added together, the result is described as the net effect. Within each of the different options, depending on the on the combination of storage type and application method, there was large variation in the net effect on profitability.

In MO1 the average farm net saving were €225, ranging from €3 to €348, for management options using the CT storage combined with the IA application method to LT storage method with the TA application method respectively (Table 5, Figure 1). In MO2, no net savings were obtained ranging from lowest net cost of €136 for the combined use of LT, TA and WSF, storage application and treatment methods. This is compared to the maximum net cost of €1043 using the combined storage application and treatment methods of CT, IA and WSF respectively.

In MO3 the net effect ranged from a mean cost of €333 to a mean net saving of €181 for the CT combined with IA and LT combined with UA methods of storage and application respectively.

In MO3c and MO3c1, as the storage period increased, the mean net effect reduced by an average of 132% to an average net cost of €466. The overall mean net savings for MO1 to MO3c1 ranged from €105 to €348 (Table 5, Figure 1). Regardless of options the greatest net saving were generated by using low cost storage facilities (LT) and the most economical method of application while maximising the nutrient content and DM response of the DSW.

Sensitivity analysis

Sensitivity analysis SA1

In sensitivity analyses SA1, as the purchase price of water increased, there was an extra saving of €1015. This allowed the total savings from using a WSF increase to €2599. In SA1 the net effect ranged from a net cost of €260 for CT x IA x WSF to a net saving of €646 for LT x TA x WSF (Table 7).

Sensitivity analysis SA2

In SA2, increasing the price for fertiliser N, P K and the value of DM resulted in a mean increase of 10% in total savings for all management options (Table 7).

Sensitivity analysis SA3a and SA3b

In SA3a, reducing the TA application rate to 36.6 m^3 per hour caused an increase of 25% in TA application costs. This resulted in the average net effect being reduced by a mean of 26%, ranging from 1% to 181% of a reduction for MO1 to MO3. In SA3b, increasing the TA application rate to 54.5^m per hour caused a reduction of 17% in TA costs. This resulted in the average net effect being increasing by a mean of 17%, ranging from 1% to 19% of a increase for MO1 to MO3c1 (Table 7).

4. Discussion

Irish Dairy Industry DSW management options

The current study simulates an Irish seasonal dairy production system in order to evaluate different strategies for efficient utilisation of DSW on dairy production systems in the Republic of Ireland. The simulation model focuses on evaluating the main factors and economic consequences of contrasting management options available for DSW. The financial consequences include, the costs associated with storage and application and the savings generated from reduced input usage and extra revenue from increased production. System simulation

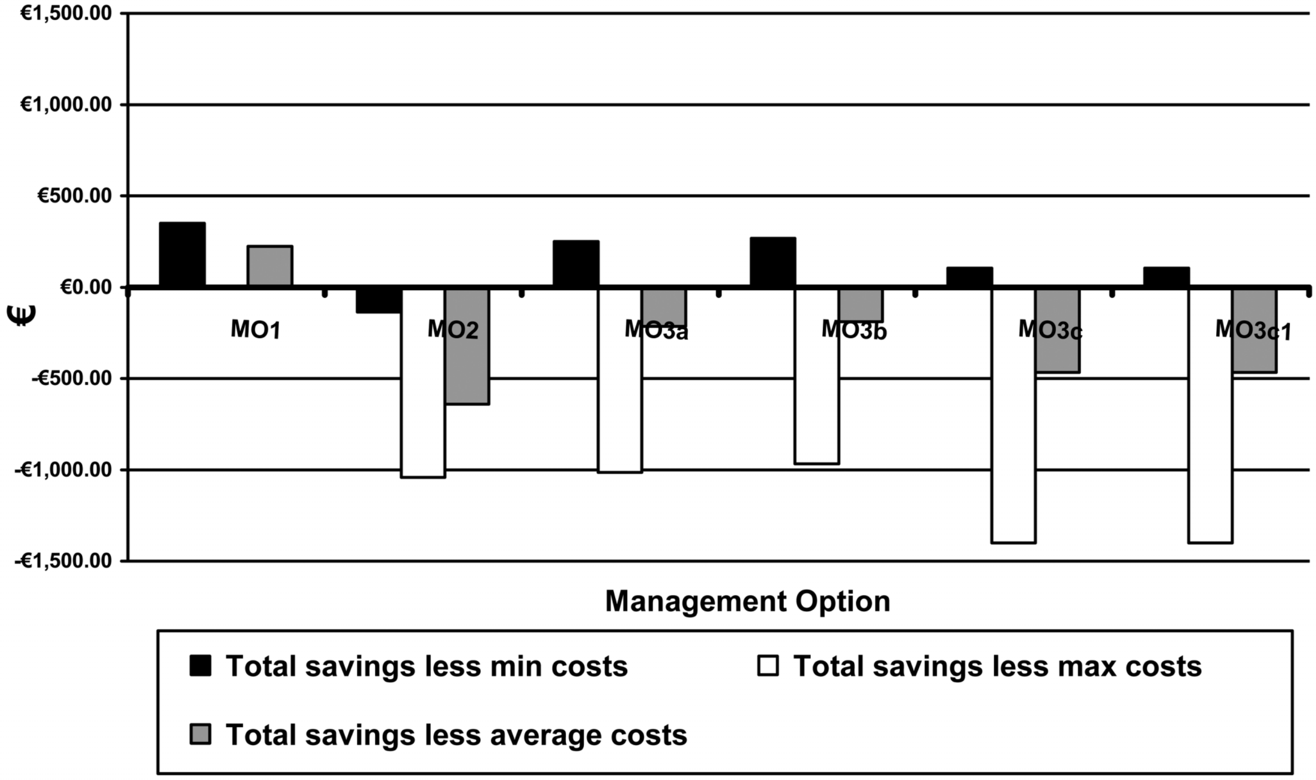

Figure 1: The minimum costs less total savings, maximum costs less total savings and average cost less total savings for management option MO1 to MO3c1

allows examination of alternative and contrasting production processes i.e. enterprise selection and resource allocation (Shalloo *et al*., 2004) without having to experiment on a real system, which may be prohibitively costly, time-consuming or simply impractical (Ryan *et al*., 2011).

Environmental legislation

In the Republic of Ireland, depending on the biological and nutrient content of DSW, it can be considered as soiled water or slurry (Minogue *et al*., 2010; S.I. 610. 2010) which dictates the storage and application practices

Table 7: Sensitivity analysis showing the economic consequences of a range of different management strategies for DSW with contrasting storage periods and methods of application for a spring calving dairy herd with 80 cows

Item	MO1[1]	MO2[2]	MO3a[3]	MO3b[4]	MO3c[5]	MO3c1[6]
Application costs TA € for SA3a[7]	€959	€192	€959	€959	€959	€959
Application costs TA € for SA3b[8]	€640	€128	€640	€640	€640	€640
Frtiliser Nitrogen savings € for SA2[9]	€346	€22	€300	€300	€296	€296
Fertiliser Phosphourus savings € for SA2[10]	€114	€5	€99	€99	€98	€98
Fertiliser Potassium savings € for SA2[11]	€282	-	€206	€206	€197	€197
Water savings € for SA1[12]	-	€2538	-	-	-	-
Dry Matter savings € for SA2[13]	€500	€41	€642	€642	€658	€658
Average-marginal saving or cost € SA3a[14]	€161	(€885)	(€262)	(€236)	(€514)	(€514)
Average-marginal saving or cost € SA3b[15]	€267	(€864)	(€182)	(€156)	(€434)	(€434)

[1]Management option 1 (MO1).
[2]Management option 2 (MO2).
[3]Management option 3a (MO3a).
[4]Management option 3b (MO3b).
[5]Management option 3c (MO3c).
[6]Management option 3c1 (MO3c1).
[7]Application costs for vacuum tanker (TA) Sensitivity analysis 3a (SA3a).
[8]Application costs for vacuum tanker (TA) Sensitivity analysis 3b (SA3b).
[9]Frtiliser Nitrogen savings € for Sensitivity analysis 2 (SA2).
[10]Fertiliser Phosphourus savings € for Sensitivity analysis 2 (SA2).
[11]Fertiliser Potassium savings € Sensitivity analysis 2 (SA2).
[12]Water savings € for sensitivity analysis 1 (SA1).
[13]Dry Matter savings € sensitivity analysis 2(SA2).
[14]Average-marginal saving or cost € Sensitivity analysis 3a (SA3a).
[15]Average-marginal saving or cost Sensitivity analysis 3b (SA3b).

which can be undertaken. The nitrates directive (S.I. 610. 2010) sets a minimum winter waste storage and application period for animal wastes. The set waste storage period ranges from 10 days for soiled water to 22 weeks for slurry depending on the location within the country and storage specifications (zones A–C1) (S.I. 610. 2010). This can increase the storage costs by more than tenfold and have restrictions on the application window during the year (S.I. 610. 2010).

System simulation, comparison of DSW storage methods and costs

The main factor influencing total storage cost is the quantity of storage required, which is a reflection of the storage period, in the options investigated this ranged from 10 days to 93 days. Similarly, as the storage period increased from zone A to C1 (MO3a to MO3c1), the minimum storage quantity increased by 45% resulting in an increase in DSW storage costs. Minogue *et al*., (2010) found that the mean DSW storage period for separate DSW was 33 days on Irish dairy farms. The CT method of storage has been shown to be the most common method of slurry storage in Ireland (Hyde *et al*., 2006) and Europe (Menzi 2002) while Minogue *et al*., (2010) had similar findings for waste water storage. The options highlighted that storage was a major cost to the system accounting for nearly 50% of total DSW costs, with CT being the most costly form of storage. The most economical method of DSW storage was the LT, which was approximately 63% cheaper than the CT form of storage. The storage costs used in this study are based on average Irish industry prices. However as tank size increases, there will be additional savings/cost reductions due to the economics of scale (Ryan 2012).

In MO1, storing DSW for 10 days and applying all year round was the most economical management strategy for DSW. However this management strategy assumes the DSW nutrient content is below the limit set by the S.I 610.2010 for soiled water. However Minogue *et al*., (2010) found that approximately 13% of DSW samples were above the limit set by the S.I 610.2010 for soiled water, putting it into the category of slurry, which requires a longer storage period and restricted application times of the year.

Storing DSW together with slurry proved to be up to 45% more cost effective per m^3 stored than storing DSW separately. This management option assumes that the on-farm infrastructure allows DSW to be stored in the existing winter slurry storage; otherwise additional costs will be incurred. This emphasises the critical importance of careful planning and management practice evaluation to assess the most economical option suitable for the farm system.

Options MO3c and MO3c1 (zones C and C1) had an extra 30 days housing period, simulating a longer winter housing period. This is typically experienced in zones C and C1 or in areas with high rainfall and reduced soil trafficability. The additional storage period increased costs by over 30% and reduced the mean net effect by more than 60% compared to zone A and B. The additional cost in MO3c and MO3c1, highlight that producing milk during the housed period and delaying spring turnout date, incurs additional costs compared to milk that is produced during the grazing period. Patton *et al*., (2012) noted that selecting the ideal calving date and turnout date to suite the geographical location will significantly reduce production costs. Animal waste storage facilities are a major cost to a system, and extra costs due to the slurry storage requirements of the nitrates directive reduce profits of a system (Hennessy *et al*., 2005). In MO3, the on farm slurry storage facilities/infrastructure and their location in relation to the milking parlour will be a major factor influencing the storage costs associated with DSW.

Application and treatment costs and opportunities

The application costs were similar across options when no treatment processes are imposed. As the efficiency of application decreased or increased (SA3a, SA3b) additional costs or savings were experienced. In the simulation, the different application methods were not differentiated by any additional associated benefits. For example, the associated benefits of the UA and IA application method would be an increased opportunity for spring application and reduced soil compaction compared to the TA method (Lalor and Schulte 2008). In Ireland short winter housing and early spring turnout are key elements of low cost grass based production, however soil trafficability is the main restriction of spring grazing and application of animal wastes (Lalor and Schulte 2008) resulting in increased costs due to the weather and soil conditions (Brereton and Hope-Cawdrey 1988). However grass growth rate and nutrient uptake by grass is low when soils are very wet with increased risk of nutrient loss (Brereton and Hope-Cawdrey 1988). The IA application method was the most expensive due the capital investment of the pump and piping required for such a system, although there would be an advantage due to convenience associated with such a system, which is difficult to capture and simulate.

Using a WSF to treat the DSW, reduced application costs by 80%, increased savings by 40% and costs by over 150% and reduced over all net savings and profitability by nearly 400%. The use of a WSF reduced the quantity of purchased water for yard washing by 80% and reduced the quantity of N recycled by approximately 80%. The use of such a bio filtration system creates a synergistic opportunity from both an economically and environmentally perspective to reduce costs and reduce any potential nutrients lost (Ruane *et al*., 2010). However based on the current costs associated with using a WSF, there was no economical benefit for using a bio filtration system. Similarly other authors investigated alternative treatment process such as, constructed wetlands, (Dunne *et al*., 2005) as a treatment process to reduce application costs, with low running and maintenance costs, which are effective at reducing biological and nutrient concentrations from influent wastewaters. However they require a large area of land which adds an economic cost to such a process.

However, in the sensitivity analysis of increased water charges (SA1), the use of a WSF increased total savings increased by more than €1000 and the net effect was an average net saving/profitability of €375, which is a mean increase of 160%. This highlights how different technologies become cost effective as input prices increase.

In the current management options investigated, the UA and TA application methods were the most cost effective. However if the volume for application increased the UA method would be 9% more economical. Lalor, (2008) highlighting that, economic benefits of different application methods can be eroded due to high costs of the system or system inefficiencies. This emphasises matching the correct management practices to a system will maximise profit (Rotz *et al.*, 1999).

Nutrient utilisation and savings

Dairy soiled water contains valuable nutrients and used efficiently will generate cost savings from reduced chemical fertiliser use and increased herbage production (Schroder, 2005; Minogue *et al.*, 2010). The average quantity of nutrients recycled created a potential total saving of €470/farm or €12 per ha^{-1}. The nutrients recycled in the farm system have the potential to produce an additional 3500 kg of herbage DM (Morrison *et al.*, 1980). The extra DM produced would allow the dairy herd increase by one cow and generate a profit of ranging €300 to €700 depending on milk price (Patton *et al.*, 2012). In all options investigated, the best economic and agronomic savings were generated from additional DM grown during the spring and summer months from strategic applications of DSW (Minogue *et al.*, 2010). However, applying nutrients to land outside of the growing season, when there is little or no agronomic response or benefit is economically wasteful and potentially damaging to the environment (Jarvis and Aarts 2000).

In the Republic of Ireland, the average fertiliser N application rate is 168 kg N ha for dairy farms stocked at 2 Lu ha (Lalor *et al.*, 2011) accounting for approximately 9% of total costs (Hennessy *et al.*, 2010). Utilising DSW effectively can reduce N input by approx 6% creating a farm saving of approximately €400. The Irish dairy herd is projected to expand by 50% by 2020 (DAFF, 2010), which will be achieved through efficient utilisation of all available resources. Nitrogen fertiliser usage is estimated to increase by 17% (Donnellan *et al.*, 2012) and utilising the nutrients in DSW efficiently would allow approximately 33% of the estimated fertiliser N increased required to be achieved at no additional cost to the system.

Management option MO3 generated an average of 1% more savings and 24% extra DM produced compared to MO1, due to a strategic application of DSW in the spring and summer and autumn when NFRV and DM response to N are at their highest (Coulter and Lalor., 2008; Minogue *et al.*, 2010). The regulations of the nitrates directive are legally binding governing slurry storage and non-spreading periods, creating a distinct competitive advantage between the different zones A to C1 in the republic of Ireland. Similarly, all EU countries have to manage and utilise their resources and nutrients efficiently. The implementation of the Nitrates Directive has set limits on the quantity of organic N which can be produced per Ha with specific application periods based on weather, location and soil conditions (Humphreys *et al.*, 2012). Within the EU depending on how DSW is classified, dictates whether it is managed as soiled water or slurry, causing a 10 fold difference in management costs. Within different EU countries, the slurry storage period ranges from circa 3 months to 10 months depending on the location and local climatic conditions (91/676/EEC). This puts Ireland with a competitive advantage in relation to minimising system costs and maximising nutrient utilisation. However regardless of location, maximising the efficiency at which resources are utilised in grassland livestock production systems will ensure sustainable and economically viable food production (Peeters, 2009 2012). This emphasises the importance of minimising production system costs in situations where milk price and N price can be volatile (Humphreys *et al.*, 2012).

Dairy soiled water future management practices

Research in low cost facilities (Regan *et al.*, 2002) has shown there is huge potential in alternative low-capital-cost housing and effluent management facilities (Ruane *et al.*, 2010). A major advantage of such low-capital-cost facilities is that they enable farmers with limited resources to put in place facilities which will allow them to gain control over the consolidation or expansion of their business (Donnellan *et al.*, 2002; Scully *et al.*, 2002). For example, the CT capital cost for extra DSW storage was over 60% more costly compared to the low cost LT method of storage. Therefore with pressure to reduce costs and in the absence of grant-aid for larger farmers it is opportune to examine alternative lower cost systems (Dillon *et al.*, 2008). In the options investigated, regardless of how DSW is classified, storage and application were the main costs. As the method of storage and application changed, the costs associated with DSW increased by approximately 2 fold. Hence the importance of investigation management options fully before making a management decision that will have serious financial consequences (Rotz *et al.*, 1999; Shalloo *et al.*, 2004).

Management and optimising of DSW

Minimising costs, increasing resource utilisation and technical efficiency are fundamental essentials in operating a successful farm business (Finneran *et al.*, 2010). In MO3, as standard good grassland managed practice, extended autumn grazing (Hennessy *et al.*, 2006; Ryan *et al.*, 2010) was practiced with animals remaining at grass until 01 December. In these options, extending the grazing season reduced the quantity of slurry storage required or being utilised by up to 40% creating an opportunity for DSW to be stored in its place. Dairy soiled water only requires 44% of the storage space which is required for slurry for the same period of time, due to the reduced volume that is generated per day compared to slurry. Utilising the on farm resources in this way reduced the requirement for excessive DSW storage, creating an economic saving for the systems in MO3 while being fully in compliance with the nitrates directive. Combining the commencement of lactation with the start of grass growth and permitted application period (S.I. 610. 2010) minimised the quantity of DSW which would otherwise have to be stored for a long period of time.

In Europe, with the future abolishment of milk quotas, for dairy farmers to maintain their incomes, expansion and efficiency will require, incorporating tight cost control, particularly with capital investment (Dillon *et al*., 2008). Seasonal milk production systems economically outperform non seasonal milk production systems, due to the low costs associated with the system (Geary *et al*., 2013). Increasing the quantity of grazed grass in the diet of milk production systems has been proven to increase overall enterprise profits (Dillon *et al*., 2008). To maximise herbage consumed, the grazing season must be extended in autumn and spring, and grazing stocking rate must be maximised. Grass must be managed to allow for extended grazing, and the efficiency with which it is grown and utilised must be optimised (Ryan *et al*., 2009). Nitrogen is an essential nutrient required for grass growth and can be a potential limiting factor for optimum system performance (Ryan *et al*., 2010). In the present study, altering the grazing season length highlighted that regardless of storage type or method of application, in a spring calving dairy production system, the costs associated with DSW reduced as the length of time spent grazing increased. Minimising the level of investment in capital costs improves the long-term efficiency and competitiveness of the production system with more opportunities for expansion (Donnellan *et al*., 2011). However, the EU Nitrates Directive (Council of the European Communities, 1991), defines limits on N per hectare, and thus puts restrictions on the expansion of dairy production in intensive, specialised farms (Hennessy *et al*., 2005). A recent study by Lips and Rieder (2005) projected that quota abolition would allow production to move to areas of competitive advantage such as Denmark, Ireland and The Netherlands, predicting that milk production in Ireland could increase by up to 39%. In response to these policy changes and fluctuations in product prices, there will be a necessity for producers to increase scale, efficiency and competitiveness through improvements in breeding programs and better farm systems management practices (Dillon *et al*., 2008).

The finding of this study are similar to other countries within Europe, regardless of storage and application restrictions, the optimal management of dealing with livestock manures and dirty water will usually be to apply them to agricultural land at appropriate rates for the benefit of soil and the crop (Menzi 2002). Combining the commencement of lactation with the start of the grass growing season allowed the most economical options for effective DSW management. When combined with a nutrient management plan, the nutrients within the DSW will be used effectively to reduce fertiliser costs, maximise herbage production and reduce the risk of water pollution (DEFRA 2010).

5. Conclusion

The options investigated in this study highlight, combining the commencement of lactation with the start of grass growth and permitted animal manure application period, minimised the quantity of DSW which would otherwise have to be stored for a long period of time. Regardless of location or storage period, this proved to be the most economical option for effective DSW management. Dairy soiled water contains valuable nutrients and maximising nutrient utilisation while minimising loss to the environment will reduce input costs and increase the economic returns of the system. Reducing system costs and protecting the environment are fundamental for the long term development of sustainable dairy production systems. The findings from this study highlight that, within the Republic of Ireland, regardless of geographical location or storage period requirement, higher savings can be attained using low cost storage and application methods for DSW. Low cost storage and application methods are combined with strategic synchronisation between crop nutrient demand and supply, by applying DSW during the growing season for the greatest NFRV and herbage DM response. This emphasises the critical importance of the proper management of slurry and soiled water both in the interests of protecting the environment, maximizing nutrient value and reducing costs.

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