LOCAL PIPELINE TRANSPORT FOR THE ENVIRONMENTALLY AND ECONOMICALLY SUSTAINABLE MANAGEMENT OF PIGGERY SLURRY

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1 INTRODUCTION

Regions with a high pig farm density require an adequate management of the effluent produced, if the environment is to be adequately protected. Manure transport is one of the most important issues of management, independently from whether a centralised management or farm-based schemes are used (Flotats et al., 2009). As pig slurry is a fluid, pipelines are an attractive option avoiding the need for road haulage (Sørensen et al. 2003). Using pipelines is a cheap way to transport livestock slurries, as observed by Bjerkholt et al. (2005). However, the costs of pipeline systems are scale dependent, as observed in the work of Ghafoori et al. (2007). Such study deals with the management of beef cattle manure in much larger volumes than it is done in this present paper.

The objective of this study is to analyse and compare the road and pipeline transport of pig slurry as part of the environmentally correct and sustainable management of pig manure. It covers three prototype pipeline systems built in two different regions in Aragón (Spain), which were funded under the European LIFE ES-WAMAR (2006-2011) project.

2 MATERIALS AND METHODS

Three different pipeline systems which are installed in two communes in Aragón (Spain): Maestrazgo County and the municipality of Peñarroya de Tastavins. In Maestrazgo, two pipeline facilities were assembled (systems A and B, as shown in Figure 1), whereas in Peñarroya de Tastavins there is just one system (scheme C).

Local conditions such as accessibility to arable land and transportation costs are key factors to an optimised manure management (Flotats *et al.*, 2009). Therefore, the design of the pipelines has been carried out according to the following principles: (i) to use gravity flow as much as possible, (ii) to substitute for road transport where it's most advantageous.

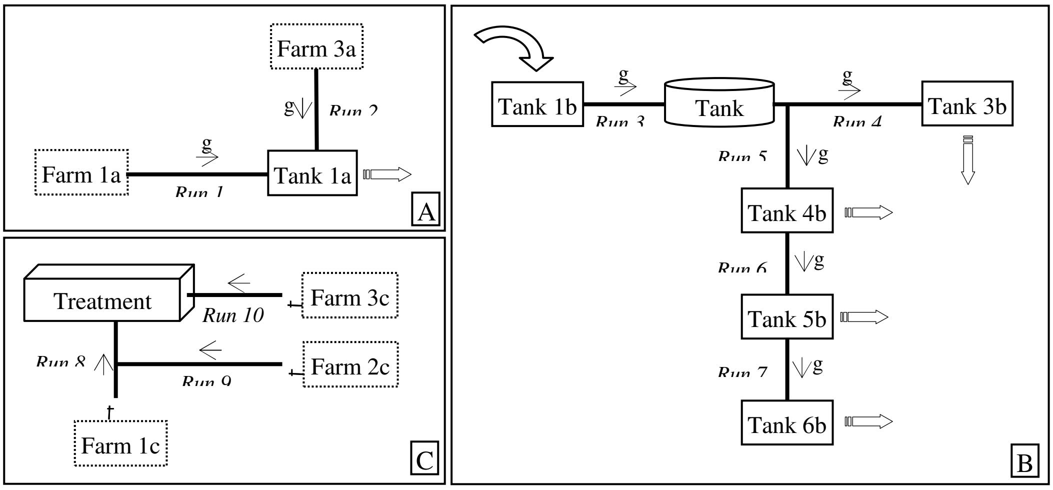

FIGURE 1 **Pipeline Schemes in Maestrazgo and Peñarroya de Tastavins. A) Cantavieja, B) Castellote, C) Peñarroya de Tastavins. (g = Gravity transport; ↑ : Pumping transport; ⇨: Collection, transport by road and application in land; ↷: Transport from pig farm to tank 1b by road transport).**

In system A, the slurry from two connected pig farms is collected by means of individual pipelines which end in a common tank close to the road enabling an easy collection of the manure. From this point road transport is used, either to directly for application to local fields, or transport to intermediate stores.

System B comprises also two parts. The first pipeline is used to transport pig slurry to an intermediate tank, and the second to distribute it from here by two separate lines to one of four small collection pits, from where it is taken for local land application. In the area of System B, not all available land is easy to access, due to the local geography of this mountainous county. Currently, in this area the vehicles are transporting the pig manure over winding roads that run over the sleep terrain. As a consequence, the delivery of pig slurry is inefficient, leading to high fuel consumption (and the related transport emissions). Thus, pipeline transport by gravity force is an alternative, facilitating the access to remote areas and increasing the local nutrient recycling.

The third pipeline, system C, collects pig slurry from three connected farms and sends it at a centralised treatment plant. Here the pig manure is biologically treated in order to eliminate the nitrogen surplus that is generated by the large local pig slurry production. Although two of the pipes run downhill, the pig slurry must also be pumped to take it out of the farm storage pits to reach the pipelines.

2.1 Pipeline characteristics

In the studied literature, very few data from previous studies were found that was useful for the pipelines design. The work of Bjerkholt *et al*. (2005) defines design parameters for pipelines transporting pig slurry. The suspended solids content in the pig slurry leads to an increased pressure loss (compared with water), which is a crucial parameter for the pipeline design, as it influences the choice of diameter and material (Ancev and Stoecker, 2006). The pressure loss term in the work of Bjerkholt *et al*. (2005) was used for the current design of the pipelines, which has been carried out with the standard Bernoulli's equation. The volumetric flow rate that was assumed for the design was 60 m^3/h.

The internal diameters (D), pipe lengths (L), differences in altitude ΔH, the pipeline materials as well as flow rates (Q) are listed in Table 1 for the individual runs. All the pipelines except run 8 have a negative slope. In system B, in order to transport pig slurry from the intermediate tank 2b to tank 6b, runs 5 to 7 are used. The difference in altitude between these two tanks is 249 m. A continuous pipeline is technically possible but this would lead to a pressure of close to 25 bar in case of pipe blockage a valve that was shut by mistake. Therefore, intermediate tanks 4b and 5b are placed as pressure breakers. At the same time these vessels are fitted with the necessary items to remove slurry. In system C, Run 9 is connected to run 8 by a junction, so that the path from farm 2 in Figure 1c is 175 m longer as the length indicated in Table 1.

The flow rates of the different routes have been determined by field trials. It can be observed that the measured values were higher than the design value of 60 m^3/h for all runs of schemes A and B, except run 4. Here, the controlling valve was not completely opened, being the same conditions for the measurements of run 5. This procedure was implemented in order to reduce foam creation in tank 4b.

TABLE 1 **Technical details and economic data of the installed pipelines**

Pipeline System	Run	L	□H	D	Material	C	C_L	Q	Q Road transp.
		(m)	(m)	(mm)		(€)	(€/m)	(m^3/h)	(m^3/h)
A	1	1051	-87	115,4	PVC	21.662	20,61	94	141
	2	45	-7.4	115,4	PVC	9.789	217,52	96,8	120
B	3	1640	-78	115,4	PVC	40.342	24,60	80,5	40
	4	1218	-108	115,4	PVC	26.683	21,91	40,9	40
	5	466	-89	133,8	Uratop®	15.597	33,47	105,2	65
	6	479	-62	96,8	HDPE	12.660	26,43		
	7	648	-98	96,8	HDPE	18.731	28,93	99,8	26,1
C	8	1122	+18	141	HDPE	51.250	45,68	48,7	35,9
	9	422	-10	96,8	HDPE	18.466	43,78	54,7	35,9
	10	923	-25	96,8	HDPE	36.479	39,54	51,3	35,9

C stand for the investment costs in €, whereas C_L represents the relative investment costs (€/m).

2.2 Economic aspects of the pipelines

The investment costs, are indicated in Table 1 in terms of absolute (€) and related costs (€ per meter of pipeline). These amounts include VAT, at 16%. The costs include all materials and corresponding work. In addition to the pipeline costs, there are ancillary items such as concrete tanks and valves, as well as the pumps for runs 8 to 10. In change, the intermediate tank of 1500 m^3 is not included in the costs, because it counts for the general infrastructure. Regarding the pipelines of scheme A, the relative investment costs of the run 2 are very high. This can be explained as the costs of commonly used accessories for the pipeline system are shared equally between both runs. In consequence, they have a stronger incident in the relative cost of this run.

The annual costs analysed in this study comprise the fixed and variable expenses. Both fixed and variable costs are determined in order to compare them to the equivalent cost for the alternative road transport. In scheme C, the energy consumption (kWh) of the pumps was determined by the electricity meter installed on the farms. The electricity is the only variable cost, as the others are related to the investment. For the financing costs a life time of 20 years is assumed, and an interest rate of 6%. Annual maintenance costs have been defined as 2% of the investment. This last item will cover replacement, repair as well as staff time.

2.3 Characteristics of road transport

The volume movements of slurry by road transport are based on a one way trip, in order to have the direct comparison with the pipeline (Table 1). For managing purposes, the overall hauling time (and distance) is doubled, since the return trip must be assumed. The time for road transport in every scenario has been measured on site.

For system A, the two pig farms, from where the slurry is collected through the pipelines produce together 9016 m^3/year. The alternative road transport, if the same slurry were carried by the lorry tankers of the local Swine Waste Management Enterprise, would have taken 107 hours. The cost of the local transport service is 69 €/hour.

In zone B, the pig slurry is brought to the arable land for nutrient recycling at a distance of 1,5 km around tanks 2b, 3b, 4b, and 6b. In total there are 194 ha of land available. The fields are only accessible by a tractor. For accessing the tanks 3b, 4b and 6b, the equivalent road transport starts at tank 1b and continues the respective alternative way to runs 4, 5 and 7. Tank 5b is not used for taking out pig slurry. The corresponding annual costs of run 6 and tank 5 are accounted for the next tank downstream, which is tank 7b. According to the local conditions and following the best practice for application of nutrient recycling the application rate was 35 m^3/ha per year. The resulting volume of pig manure applied to the 194 ha is 6790 m^3 per year. The local price for the service of a tractor with a 10m^3 tanker is 28 €/hour.

In scenario C, the total transported volume, 15.755 m^3, corresponds to the year 2009 and is 41% of the total volume delivered to the plant. The road transport is carried out by a contracted service for 1,61 €/m^3. The fuel consumption of the truck used for local transport is 12 l/h.

2.4 Environmental aspects: GHG emission assessment.

The environmental impact of pig slurry transport by pipeline has been assessed from the greenhouse gas emissions produced. The avoided emissions of the alternative road transport have been determined as 1 kg of diesel produces greenhouse gas (GHG) emissions of 3,78 kg CO_2-eq. (Ceotto, 2005). Whereas 1 kWh electricity releases GHG as 0,72 kg CO_2-eq. (Murphy and McKeogh, 2006).

3 RESULTS AND DISCUSSION

The results of the economic analysis and the GHG balances are set out in Table 2. The pressurised pipelines of system C have higher relative investment costs, which is due to the pumps assembled at the farms. The mean relative cost of the pipelines in scenario C is 43 €/m, whereas the mean for zones A and B is 26 €/m (not considering run 2). Hence, the pressurised pipelines are 65,5% more expensive than the gravity driven pipelines.

All pipeline systems generate net savings. Systems A and C have similar periods for the return of investment, which is significantly higher for system B. As system C has higher relative investment costs and annual costs than system A, more volume has to be managed to obtain a similar return period. Comparing systems B and C, it can be seen that the first year costs and gross savings are similar, but the net savings are much higher for scenery C. A way to reduce the period of investment return in zone B is to increase the transport of pig slurry to be applied on more arable land found at larger distance from the pipeline. The results are in agreement with similar studies such as Ghafoori *et al.* (2007) and Sørensen *et al.* (2003), although the sizes of the analysed schemes are different.

In system C, the energy consumption for the three runs varied from 0,048 to 0,173 kWh/m^3. Little energy consumption corresponds to the short and medium pipeline, which both have a slight downhill profile. In contrast, the highest energy consumption is observed at the longest pipeline with an uphill profile.

TABLE 2 **Economic evaluation of pipeline transport in the three scenarios relative to road haulage.**

Pipeline System	Total volume	First year costs		Gross Savings		Net savings		Investment return	GHG emission savings
	(m^3/year)	(€/year)	(€/m^3)	(€/year)	(€/m^3)	(€/year)	(€/m^3)	Year	(kg CO_2-eq./m^3)
A	9.016	4.089	0,45	7.388	0,82	3.300	0,37	8th	0,64
B	6.790	14.822	2,18	22.005	3,24	7.183	1,06	13th	2,61
C	15.755	14.099	0,89	25.385	1,61	11.286	0,72	9th	0,9

A tractor consumes a mean of 9 l diesel per hour, for which a GHG emission saving for avoided road transport can be determined as 2,6 kg CO_2 eq./m^3 pig slurry. The GHG emission savings because of the not consumed diesel fuel vary from 0,64 to 2,61 kg CO_2-eq./m^3 as they depend on the local alternative road transport of the study zones. The electricity consumption by the pumps in scenario C has little effect on the GHG balance. The main environmental advantage lies with the avoided delivery by road transport.

4 CONCLUSIONS

In all three studied scenarios, the use of the pipelines for the pig slurry transport enabled to reduce the transport costs and, in consequence, the costs of general pig slurry management. On the strength of these encouraging results, the pipeline system C is currently being extended to connect more farms. Furthermore, remote arable land is made accessible by the pipeline thus increasing nutrient recycling in a sustainable and economic way.

In the comparison, sensibility of the economic data was observed for both the cost of the alternative road transport and the total managed volume. Future work is required to determine more precisely the relevant management data as a support for planning pipeline implementation.

Technically it's possible to transfer higher volume rates for pipelines in comparison to road transport. The observed technical issues of pig slurry transport by pipelines at full scale deserve a wider discussion.

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