# A Slurry Spreader to Meet Farming Needs and Environmental Concerns

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## SUMMARY

The splash plate slurry spreader is inexpensive and robust but it is not environmentally friendly. It releases most of the ammonia ($NH_3$) in slurry, emits strong odours and distributes the remaining nutrients unevenly. The object of this report is to identify improvements to slurry spreaders that may eliminate these shortcomings.

Several gases are released during and after slurry spreading. $NH_3$ contributes to acidification of the environment and is emitted almost entirely from agriculture.Over 30% of European $NH_3$ emissions come from slurry spreading.The Gothenberg agreement (UNECE, 1999) requires a reduction in national $NH_3$ emission to 8% below 1990 levels. Emission of this gas from band, TF (trailing foot) and injector slurry spreaders is 40, 40 and 20% respectively of that from conventional splash plate machines. A switch to spreaders with lower emissions would provide sufficient reduction to satisfy the Gothenberg objective.

Odour from livestock units gives rise to many complaints but there is little evidence that it is a health hazard. Emission of the vapours from slurry spreaders is in the order; (splash plate)>(band)> (TF and injector). Other gases (methane and nitrous oxide) are released primarily after injection.

Infection of humans by slurry-borne organisms is not common. In general the differences between spreaders in regard to pathogens are not significant but this conclusion may not apply in all cases.

Slurry nutrients amount to 40% of the N and 65% of the P required in agriculture. Several commercial and experimental methods exist to measure slurry nutrient content. Field application using a splash plate and vacuum tanker gives highly variable distribution. Any of the other spreaders reviewed here combined with a fixed displacement pump achieve more uniform application. Accurate spreading reduces the need for excess application so losses to water from soil are reduced. This conforms to the Water Framework Directive. Deep injection and incorporation can reduce loss of P from slurry but other spreading methods will not normally reduce the risk of P loss at spreading time.

The proposed tanker consists of a closed tank with running gear fit for road and field conditions. A TF spreader is fitted at the back. The slurry is handled by a fixed displacement pump which fills the tank or empties it through the spreader. The pump must be protected from obstacles so an intake filter or chopper filter should be included. This slurry spreader would reduce emission of $NH_3$ and odour and increase the recycling of slurry nutrients to crops. It is more expensive than splash plate machines but if widely adopted it could be an economical solution to the UNECE requirement to reduce $NH_3$ emissions.

Alternatives to improving spreaders exist. These include digesting slurry, and reducing emissions from livestock housing and slurry storage. With the exception of digestion these offer poor prospects of success especially in relation to odour reduction and exploitation of slurry nutrients. The cost of providing this equipment on Irish farms is likely to be between €200m and €800m and depends on the options chosen.

## INTRODUCTION

Slurry spreading as a farm management practice is contributing to environmental degradation and needs major improvements. Society requires a reduction in emissions to air during spreading operations. Legislation at national level will require a reduction in ammonia ($NH_3$) emission while the general population demands reduced odours. It is no longer acceptable to spread nutrient rich material onto land at excessive rates as this can contribute to water pollution. The quality of slurry spreading must improve if national air and water quality targets are to be met. Increases in slurry storage on farms are required under the Nitrate Directive 91/676/EEC so many additional spreaders will be needed. This creates an opportunity to improve equipment.

The objectives of this project are two-fold:

- Identify the most appropriate slurry spreading systems for use on Irish pig and cattle farms on the basis of overall performance, environmental acceptability and relative cost of the equipment.
- Justify the selection in terms of reduction in $NH_3$ loss, odour abatement and improvements in nutrient efficiency relative to splash plate equipment.

A literature review was used to assemble the relevant information. Data from published sources were tabulated to present clear comparisons under key headings. This information was used to select the best spreading system. A financial assessment was prepared to indicate the likely cost of upgrading equipment on farms.

There are several types of slurry spreader in Ireland. The vacuum tanker with a splash plate spreader at the back is used on most livestock farms. It offers the advantage of reliable operation at low cost. The disadvantages for the environment are unpleasant odours, emission of $NH_3$ and uneven application of N, P and K to the soil. Other spreaders offer reduced emissions of $NH_3$, odour reduction and improved use of nutrients. The splash plate spreader and alternative designs are shown in Fig 1.1

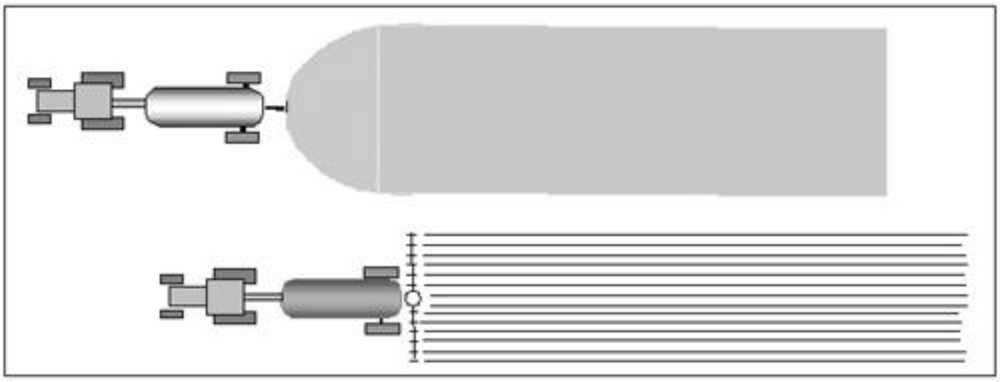

Fig. 1.1: Splash plate spreader and alternative spreader (band, TF or injector)

# REVIEW

Atmospheric $NH_3$ contributes to acid deposition on lakes and sensitive eco-systems. Virtually all of the gas originates in local agriculture sources with only 15% originating outside the State. Lee (1999) estimated the value of the loss at €65 m $annum^{-1}$. It is washed out of the air by rain so it accumulates most in areas with high rainfall. Ammonia is considered to be the most significant of three acid precursor groups affecting Ireland (Stapleton *et al*., 2000). Under the Gothenberg agreement (UNECE, 1999) Ireland has undertaken to reduce emissions of $NH_3$ by 8% below the 1990 level of 112,000 t before the target year 2010. By that year, under conditions of no change, emissions are expected to rise to 131,000 t. Therefore a reduction in emissions exceeding 8% may ultimately be required (EMEP, 2005). According to this source, emissions in Europe reduced by 20% between 1990 and 2000. However emissions in northwest Europe showed little reduction in this period and in 2000 Ireland had achieved less than 40% of the reduction required under the Gothenberg agreement.

Odour emission during land spreading is the source of many complaints about agriculture. It is an integral part of livestock farming especially where manure is stored for long periods under anaerobic conditions. Techniques are available to reduce odours but these often involve added cost without any economic benefit to the enterprise. Odour emission is one of the issues included in this study.

Production of cattle and pig manure in Ireland totalled almost 40 million tonnes of wet material in 1998 (Stapelton *etal*., 2000). This contained 200,000 t N, 30,000t P and 200,000 t K which represented 50%, 60% and 130% respectively of the nutrients applied to farms in fertilizer that year. Due to losses and poor availability very little of the Nitrogen (N) in slurry is taken up by plants. A large reservoir of nutrient such as this must be managed carefully if maximum economic benefit is to be obtained at minimal environmental risk. Improvements to spreading uniformity can reduce the variability of slurry placement to an acceptable level. This reduces the need for excess application to ensure adequate fertilization of the entire crop.

The concentration of P in overland flow increases with the concentration of the element in soil (Tunney *etal*., 1998). At a time when excess P in surface water is the primary environmental concern, soil P levels should be no higher than the level required for agriculture. If the technology exists to enable widespread adherence to recommendations in this regard then it should be adopted at the earliest opportunity.

## Emissions to air

A number of the gases that emanate from agriculture have detrimental effects on the atmosphere. They include greenhouse gases, acid precursors and odour. Convery, (2000) reported that the proportion of these gases that originate in agriculture is considerable. Methane ($CH_4$) and nitrous oxide ($N_2O$) from agriculture account for 45% of all greenhouse gases generated in Ireland. The other main group of atmospheric pollutants includes the acid precursors sulphur dioxide ($SO_2$), nitrogen oxides ($NO_x$) and $NH_3$. These contribute to acidification of the environment and the eutrophication of forests and other ecosystems. The agricultural component of acidifying gases adjusted for impact on the environment is 48% according to Convery (2000). Odour does not represent a hazard but is a public nuisance that should be reduced to an acceptable level.

### Ammonia

The distribution pattern of $NH_3$ over Ireland has not changed over the last 20 years but the rate of deposition has increased. In 1990 The Irish national emission of $NH_3$ was reported to be 112 kt $y^{-1}$ (EMEP 2005). Due to increased stocking and use of chemical fertilizer this value is expected to rise by as much as 25% by 2010. Ammonia emission arises solely from agriculture with manure the single largest source. Land spreading, animal housing and pasture each generate approximately 25% of the total.

According to the UNECE Gothenburg Agreement $NH_3$-emission in 2010 should be 8% below the 1990 level. It is envisaged that changes in farm activities will be encouraged to bring about reductions in emission. Changes already in train, such as the decoupling of EU farm payments from farm enterprises, could support this trend by, for example, reducing stock numbers. Land spreading offers the best possibility for reduction of emissions (Convery, 2000).

The sources of $NH_3$ emission are almost entirely from agriculture. The gas originates in the urine and faeces of livestock. The relative proportions from each farming activity are given in Table 2.1 for four countries; Ireland, UK, Netherlands and Germany. The data for the UK and Netherlands suggest that emissions from livestock housing are greatest. The other two data sets indicate land-spreading as the largest source of $NH_3$. The variability can be largely explained by combining housing with storage as these two are often combined in practice. In this context, the country with the shortest housing and storage period, Ireland, has the lowest relative emission. Netherlands has the longest housing period and the highest emission. Germany lies between these two countries with respect to both parameters.

**Table 2.1: Sources of $NH_3$ compared**

| Source | Ireland[a] (%) | UK[b] (%) | Netherlands[c] (%) | Germany[d] (%) |
|---|---|---|---|---|
| Housing | 32 | 48 | 66 | 19 |
| Storage | 5 | 10 | 3 | 24 |
| Pasture | 30 | 12 | 11 | 15 |
| Land spreading | 33 | 30 | 20 | 43 |

Sources: (a) Convery (2000), (b) Pain (2001), (c) Mosquera, (2002), (d) Iserman (1990)

The sources of $NH_3$ within agriculture include the following:

*Pasture:* Ammonia is emitted from dung and urine deposited on grassland. It is also emitted from soil but the amounts are very small (Mosquera, 2002) .

*Housing:* Ammonia is released with ventilating air from manure and faeces in housing. Emissions increase with the size of the area covered by manure, the residence time of the manure in the building and with temperature. Ammonia lost in housing is unavailable at spreading.

*Storage:*Where the slurry store is under a livestock building it is considered part of that structure but sometimes a separate tank is used. If the slurry surface is uncovered $NH_3$ can escape to the atmosphere.

*Land-spreading:* This is a major source of $NH_3$ in Irish agriculture. The gas is emitted during and after spreading (Fig 2.2). Machines using splash plates maximise exposure of the slurry to the air and allow more production of $NH_3$ than other spreaders. Phillips et al. (1991)

recorded a peak emission of 45 kg $NH_3$-N $ha^{-1}$ $d^{-1}$ immediately after spreading, reducing to approximately 5 kg $NH_3$-N $ha^{-1}$ $d^{-1}$ for the following 4 days. If slurry is deposited directly in the soil by injection, emission can be almost eliminated. Emission is sensitive to weather (temperature, wind speed, radiation and relative humidity) and to slurry properties (total $NH_3$ nitrate content of the slurry) and application rate. Incorporation of slurry on tillage ground offers a large reduction in $NH_3$ loss, provided the slurry is buried immediately. With rapid incorporation the plough offers the best control of emission but its work rate is slow and may not match that of the slurry spreader. Other tillage machines have higher output and can therefore provide lower emissions overall (Huijsmans et al., 2003).

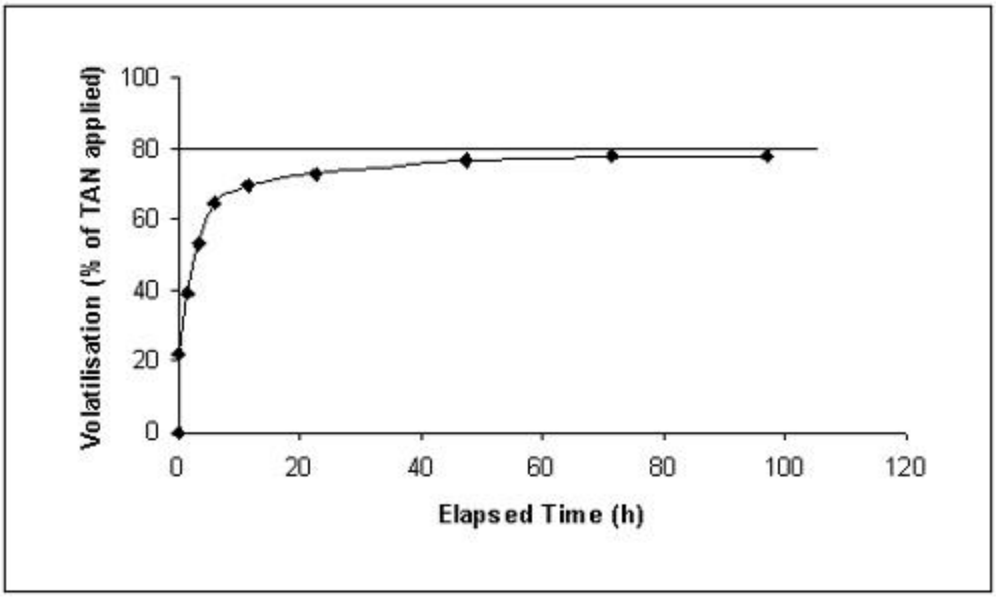


**Fig. 2.2:** Idealised curve showing cumulative volatilisation of $NH_3$ from slurry from the time of spreading at time zero to 96 hours later (Huijsmans, 2003).

Ammonia is emitted during spreading, but the largest part of the loss occurs in the 3 to 4 days after the event. Losses are sensitive to weather during this period. They increase with temperature, wind speed and radiation but reduce with humidity. So a good spreading day is cool and calm with high humidity. This should not conflict with the requirements to reduce water pollution. These include the recommendation that a forecast of no heavy rain for 48 hours must be in place on the spreading day.

Management factors offer possibilities for improvements (Huijsmans, 2003). Application rate has a strong influence on emission and for example a reduction from 40 $m^3$ $ha^{-1}$ to 30 $m^3$ $ha^{-1}$ would reduce emissions by half, on average. Allowing longer grass at spreading also reduces emissions but the benefits are less. The TAN (total amoniacal nitrogen) content of the slurry in Dutch trials was 0.24% to 0.27%. Most of this is lost by splash plate spreaders. Choice of spreading equipment has a major impact on N loss to the atmosphere with emission from improved spreaders 40% to 90% lower than from splash plate machines.

One possible alternative to the slurry spreader proposal involves control of emissions from animal housing. The requirement for ventilation in these buildings would make it very difficult to achieve large reductions in emissions here. The associated outdoor slurry stores could be covered relatively easily and this would provide a small reduction in $NH_3$ release. However, savings in this area could be lost in the field if slurry spreaders are not improved.

## Odour

Modern intensive farming has introduced systems with more intense odours than commonly experienced in the past. Livestock production has given rise to more complaints than any other activity. While odours from this sector are a major nuisance there is little evidence that they pose a health risk to the public at large (Burton and Turner, 2003).

Odour measurement is a developing science. The number of known compounds in odour from livestock housing or waste was 75 in 1984 (Barth *et al*., 1984), 168 in 1992 (O' Neill and Phillips, 1992) and 331 in 2001 (Schiffman *et al*., 2001). Due to the ephemeral nature of odour, data are highly variable and differences are difficult to establish. It is made up of several compounds. Although measurement techniques exist they do not accurately represent perceived odour sensation. Odour is carried as gas and aerosols created during slurry spreading and on dust particles from livestock housing and slurry storage (Schiffman *et al*., 2001).

Odour is expressed in odour units (OU). This value represents the number of dilutions required to render a smell detectable by no more than 50% of the staff working on an olfactometer. Carney and Dodd (1989) measured odour emissions from storage facilities holding agitated slurry of poultry, pigs, and cattle. Odour concentrations of 222, 200 and 167 OU respectively were recorded. Samples taken immediately behind a small vacuum tanker averaged 1060 and 2020 OU for cattle and pig slurry respectively (Pain *et al*.,1991). Odour concentration is less behind spreaders which place the slurry in bands or slits. Pain and Misselbrook(1991) recorded concentrations behind a splash plate spreader with a high of 59 OU after spreading and a low of 15 OU after 5 days. Corresponding values after a shallow injector were 33 OU initially decreasing to 10 OU five days later.

The unpleasant odours from slurry are due to anaerobic decay processes within the material. A large number of compounds are produced. Volatile fatty acids are the most important group and are commonly reported as being a major indicator of the offensiveness of odours emanating from slurry. Concentration of volatile fatty acids ranges from 0.4 to 2.7%. Sulphur-containing compounds are not so plentiful and are derived from amino acids in urine. Hydrogen sulphide is in this group. Volatile amines also contribute. Odour from pig houses varies three-fold over the course of the fattening period (Brose *et al*., 2001).

The emission of odour from slurry spreading is affected by the condition of the slurry. Most slurry coming from storage is in anaerobic condition with a wide range of malodorous compounds. Burying the slurry by incorporation or injection is the best method to reduce odour. Spreading slurry with a band or TF can give a reduction in odour similar to shallow injection. Where slurry has a large concentration of volatile odorous compounds some odour will be emitted for a week or more after spreading.

Treating the slurry by aeration removes BOD and, prior to spreading, this offers the possibility to significantly reduce malodour in the field. An aerobic digester consists of a tank or lagoon for slurry with an agitator or compressor to introduce air into the liquid. Slurry is pumped into the tank and treated liquor is pumped out intermittently or continuously. Foam frequently forms on the surface and this must be accommodated in the digester. The tank may be insulated to retain heat and to raise the temperature. Aeration may reduce BOD by 90% in three to four days and reduce odour significantly (Burton, 1992).

An anaerobic digester can also reduce odour at spreading. It consists primarily of a simple closed tank with a mixer to distribute material. The tank is normally heated to 35◦C and process time is 18 to 20 days. The process can consume 70 to 90% of chemical oxygen demand (COD). The biogas produced contains methane, carbon dioxide and small quantities of other gases. Most of the digestible material in the slurry is broken down so the effluent does not have an offensive smell. The mineral nutrients remain and the treated material can be spread directly on land or separated into liquid and solid fractions (Burton and Turner, 2003).

Chemical additives can be used to reduce or mask odour for short periods. They are generally less effective than digestion and are available at a similar cost.

### Other gases

Emission of $N_2O$ is associated more with injection than with surface spreading methods (band, TF and splash plate). Like $NH_3$ the emission of $N_2O$ is strongly influenced by weather and soil conditions. The injection slit may develop anaerobic conditions and this favours the evolution of $N_2O$ and $CH_4$. The amount of N released to the atmosphere by this mechanism is small but the potency of $N_2O$ as a greenhouse gas could make this loss significant. Chadwick *et al*., (2000) found that 3.14 kg $N_2O$-N $ha^{-1}$ were emitted after injection compared to 0.88 kg $N_2O$-N $ha^{-1}$ after surface spreading. Flessa and Beese (2000) obtained similar results in a laboratory trial. They also measured higher losses of $CH_4$ from the soil after injection compared to surface spreading but again the quantities were small.

## Pathogens

Slurry may be contaminated with one or more organisms from a large group of pathogens. These develop in slurry under the livestock house or slurry store. They are transferred to the field by spreading where some organisms can persist for a period of days, weeks or months. This suggests that infection of humans from spread-lands should be common but in fact disease transmission rates are very low. The risk of infection is real but in many cases it is so small that control measures are difficult to justify.

There are many different pathogens that occur in slurry and these give rise to a variety of diseases (Burton and Turner, 2003). Bacteria are the most common source of zoonotic disease. Bacterial pathogens include *Salmonella,E. Coli 0157* andgenus *Mycobacterium* among others. The main reservoir of *Salmonella* is in the intestinal tract of animals. It transfers to humans by food products. Infections are rarely fatal with mortality estimated at only 1 per 1000 cases in the EU. *Cryptosporidium* is one of a second group, parasites. This organism produces oocysts which are viable under a wide range of conditions. When the oocysts enter the gut of an animal or human, the sporozoites exit from the oocyst, attach to the gut wall and multiply rapidly. The resulting diarrhoea lasts 10 to 15 days in neonatal lambs and 2 to 3 weeks in humans. Viruses include *Foot and Mouth Disease virus,* and *Aujesky's virus*. The former causes a highly infectious disease of cloven animals. Spreading easily by wind and by direct contact it can have severe economic impact in areas affected. The latter is a disease of pigs which causes a mild respiratory disease in adult pigs but high mortality in piglets.

A wide range of methods is available for the control of pathogens. These include short and long term storage of manure in tanks and lagoons. Different combinations of temperature and time serve to reduce or effectively eliminate pathogens in storage or purpose-built reactors. Composting is effective provided temperatures rise to 55 $^{o}$C (Burton and Turner, 2003). Aeration has achieved a similar effect by means of elevated temperature, free $NH_3$ and predation by aerobic microbes. Anaerobic digestion can also reduce pathogen counts. Chemical treatment of slurry and livestock housing is used primarily after the outbreak of a notifiable disease.

The method of spreading slurry can affect the survival of pathogens (Burton and Turner, 2003). The splash plate spreader generates an aerosol that may be contaminated and which can spread over a wide area. However, because the slurry is spread very thinly over the surface, it is exposed to drying, freezing, UV radiation and soil pH, all of which can reduce the viability of microorganisms. Therefore the pathogen counts in the slurry spread by splash plate reduce more quickly than those in slurry from other spreaders. With the latter machines, decontamination of the slurry takes longer as the pathogens are protected by both slurry and soil. Different periods in the field are required to reduce specific pathogens to a safe level. For example *Salmonella enteritidis* spread in cattle slurry endured for 15 days on a loam soil but persisted for 10 days longer on a podsol soil. Also *E. Coli* persisted for 2 days on a peat soil with a pH of 2.9 but in a peat soil at pH 5.6 it lasted for 100 days (Mitscherlich and Martin, 1984). Henry *et al*. (1993) applied contaminated pig slurry to pasture and bare soil. Salmonellae were isolated from the pasture 2 months later and from the bare soil 8 months after spreading. Further examples are given in Table 2.2)

**Table 2.2: Survival of *S. dublin* in faeces and soil (Burton and Turner, 2003)**

| Survival in faeces | | Survival in soil | |
|---|---|---|---|
| **Environment** | **Time (days)** | **Environment** | **Time (days)** |
| Stored cattle slurry | 27 | Spread on soil, 15 cm deep | 300 |
| Pig slurry, 7°C | 90 | - | - |
| Slurry | >80 | - | - |

The risk of bacteria, viruses and oocysts of parasites spreading via surface water is high even where the number of organisms is small. The main route for the transmission of *Cryptosporidia* is by this route. Soil is a good filter and protects groundwater. When the organisms *E. Coli* and *Salmonella* are spread in pig slurry they can reach a depth of 1.6 m – 1.8 m in the soil (Niewalak, 1994). This is below the water table in many areas. If only small numbers of *Salmonella* reach the groundwater the risk is small, but similar information is not available for viruses and oocysts of parasites, especially those of *Cryptosporidia.*

## Impact of slurry spreading on water pollution

Animal manure has been implicated in many water pollution events. These include diffuse losses after slurry has been spread in the field. Nutrient losses in overland flow are greatest when very wet weather occurs immediately after spreading. The risk of significant loss persists for the following three weeks or more. Losses reduce over time as nutrients in the slurry are washed into the soil or over the surface (Sherwood, 1992). The relevant code of good practice advises against spreading when heavy rain is forecast in the 48 hours after the event. Spreading is also restricted in November and December (DAFF and DOE, 1996). Further restrictions are anticipated under the Nitrate Directive. Aspects of the risk of water pollution after slurry spreading are illustrated in Fig. 2.3.

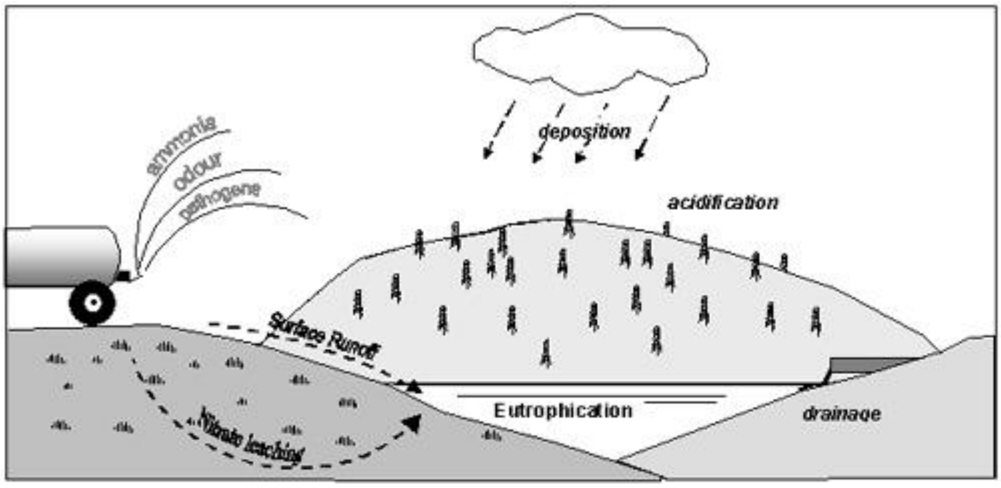


**Fig. 2.3**: Potential soil water and atmospheric activity that can result from spreading and which can lead to eutrophication of surface water and acidification of vulnerable eco-systems (after Burton and Turner, 2003).

Slurry is clearly a hazard to surface and ground water, but this is due more to management than to the choice of spreader used. The splash plate slurry spreader distributes the slurry unevenly and this leads to excess application to ensure adequate nutrient at every part of the field. Application above the recommended level is less likely with more precise spreaders.

In most cases, especially where the soil is very dry or stony, shallow injection equipment allows slurry to come to the surface of the soil (Rodhe, 2000). The risk of pollution is then similar for all four spreading methods mentioned (splash plate, band, TF and shallow injection). Sometimes, slurry is buried below the soil surface by incorporation or deep injection. The risk of pollution in overland flow is reduced in these cases but the risk of loss by nitrate leaching remains, especially where nutrient application is greater than plant requirements (Shah *et al.,* 2004).

Experimental investigations at the plot scale have shown that the build-up of soil P is the major factor determining the quantity of P lost from grassland to water. Reduction of P losses from grassland is a requirement under the Water Framework Directive. The concentration of P at the soil surface should be maintained at the lowest level compatible with agronomic production to minimise the threat to water quality. This will normally mean a soil test P level in Index 2 (3.1 to 6.0 mg $l^{-1}$ P) or Index 3 (6.1 to 10 mg $l^{-1}$ P) for grassland. Where these soils are at Index 4 (greater than 10 mg $l^{-1}$ P) chemical fertiliser P applications should be avoided and manure P inputs should be minimized (Tunney, 2005).

## Nutrient management

The nutrients in slurry are a major part of all the plant nutrients used in Irish agriculture. They should be applied uniformly to allow maximum recycling through crops. It is possible to determine the nutrient content of the organic material so that optimum application rates can be calculated. The distribution of nutrients in slurry does not normally match plant requirements so additional chemical fertilizer is required. Appropriate timing of spreading operations can reduce nutrient losses in the field.

### Nutrient content of slurries

The amounts of slurry available in Ireland are considerable as cattle, pigs and poultry produced 37Mt, 2.6Mt and 1.8Mt, respectively, in 1998. This slurry contained 40% of the N and 65% of the P required in agriculture. Knowledge of the nutrient content of slurry is important if it is to be treated as a fertilizer (Tables 2.3 (a) & 2.3 (b)). Values are broadly similar in Ireland and other European countries. However the P content of Irish slurry appears to be lower than elsewhere and this may reflect the greater use of grass in Ireland. The data are extremely variable with, for example, the mean for DM of cattle slurry given as 65 kg $m^{-3}$ in the range 15 to 123 and the mean for P in poultry slurry as 8.9 kg $m^{-3}$ in the range 0.9 to 15 (Burton and Turner, 2003). The data in Tables 2.3 (a) & 2.3 (b) are national or Europe-wide averages and do not indicate accurately the values on individual farms.

**Table 2.3 (a): Nutrient content of slurry in Ireland (kg $t^{-1}$) (DAFRD, 2001)**

| Manure Type | Dry Matter | Nitrogen | Phosphorus | Potassium |
|---|---|---|---|---|
| **Cattle** | 69 | 3.6 | 0.6 | 4.3 |
| **Pig** | 32 | 4.6 | 0.9 | 2.6 |
| **Poultry** | 240 | 14.2 | 5.1 | 5.7 |

**Table 2.3 (b): Nutrient content of slurry in Europe (kg $m^{-3}$) (Burton and Turner, 2003)**

| Manure Type | Dry Matter | Nitrogen | Phosphorus |
|---|---|---|---|
| **Cattle** | 65 | 3.9 | 1.3 |
| **Pig** | 51 | 4.8 | 2 |
| **Poultry** | 170 | 11.1 | 8.9 |

Several methods have been suggested to measure the nutrient content of slurry. A hydrometer was proposed by Tunney and Bertrand (1989) which uses a straight-line correlation for all slurries to relate density to dry matter content and to the content of N, P and K. This method was not widely adopted. Zhu *et al*., (2003) proposed separate relationships for slurry from pigs at three different stages of development and achieved high correlation coefficients. Correlations relating slurry density with N and P concentration achieved high Rsq ($R^2$) values with slurry from finishing pigs (Fig 2.4 (a)) but low Rsq values with mixed slurry from all types of pigs (Fig 2.4 (b)). They quote errors of +/-10% to +/-17% for nutrient content by the rmethod in Fig 2.4 (a). Commercial instruments based on colorimetric measurements of chemically treated slurry have been described as adequate (Tunney and Bertrand, 1989 and Walraven and Rheenen, 2000).

In a comparison of four methods for determining the N, P and K content of slurry a Rapid Laboratory Method and Mespro, a method using a computer model, gave reliable results. However a simple balance method and an in-line sensor on a slurry tanker were not sufficiently accurate to be useful (Carton and Lenehan, 1997).

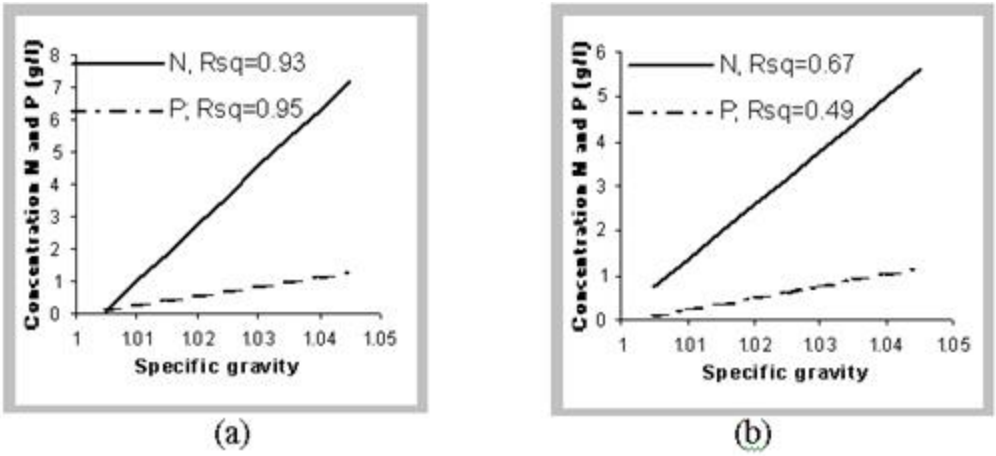


**Fig. 2.4:** Predicting N and P concentrations in pig slurry from specific gravity for: (a) finishing pigs only; (b) all types of pigs (Zhu *etal.*, 2003).

### Nutrient application and crop response

Slurry spreaders with a distributor and multiple outlet pipes offer more uniform application of slurry and more efficient use of nutrients, especially N, than splash plate machines. The former achieved values for lateral spreading CV (coefficient of variation, a measure of evenness of distribution) of 10% to 15% (Carton and Lenehan, 1997; Oh *et al*., 2004). Trials in grassland have shown that applying slurry by band or TF spreader yielded 20% more grass than spreading by splash plate (Binnie and Frost, 2003). Kiely (1988) indicated significant improvements in grass dry matter yield when slurry was spread by injection and band spreading rather than by splash plate.

The nutrients in slurry can be recycled to support crop growth. For this reason application rate must conform to the nutrition requirement of plants. The mass ratio of N, P and K in slurry does not usually match crop requirements so additional fertilizer is needed.

Determination of the ideal application rate requires knowledge of slurry composition, application rate of the slurry and the requirements of the crop. Slurry composition may be estimated from standard tables (DAFF & DOE, 1996) or a representative sample may be sent for analysis. Sampling is difficult as slurry settles into strata with solids on the bottom, liquid in the middle and a crust on top. Agitation reduces the variation and allows a representative sample to be taken. Several methods of analysis are available and some of these may delay spreading. The slurry may need to be agitated again before application in the field.

## Tankers

A slurry tanker may consist of a fully enclosed tank or an open top tank with equipment attached to allow it to fill and empty safely. Equipment includes running gear, brakes and lights to permit safe operation on the road. Tyres appropriate to the conditions under which the tanker is likely to operate are also included.

Slurry tankers vary in capacity from about 3.5 $m^3$ to 16 $m^3$. The weight of the tanker combined with the weight of slurry can approach 20 t so choice of tyre is important. It should suit the load applied and conditions in the field. Several options are available from manufacturers.

Additional equipment is required to allow the machine to function. A spreader, a pump and associated pipe work are necessary. Spreaders and pumps are discussed elsewhere.

## Spreaders

### Splash plate

Splash plate spreaders are popular as they are simple, reliable and economical. They suffer few obstructions and are less affected by slopes than other machines. However the emission of odour and $NH_3$ are high and the spread pattern is more variable than that of other machines (Fig. 2.5 (a)).

This type of spreader is supplied in various forms. The basic splash plate consists of a straight pipe with a rubber nozzle directed at a metal plate. It is mounted at the back of a slurry tanker. The nozzle can expand to allow obstacles to pass through. It creates a jet that is directed at the metal plate. Slurry is thrown upwards in a broad plume allowing a slurry aerosol and $NH_3$ to be carried away on the wind. Slurry covers most of the crop. A minor development of this spreader is a downward trajectory splash plate where the slurry is deflected downwards to reduce exposure to the air. Some designs include two or three outlets on a boom to increase spread width.

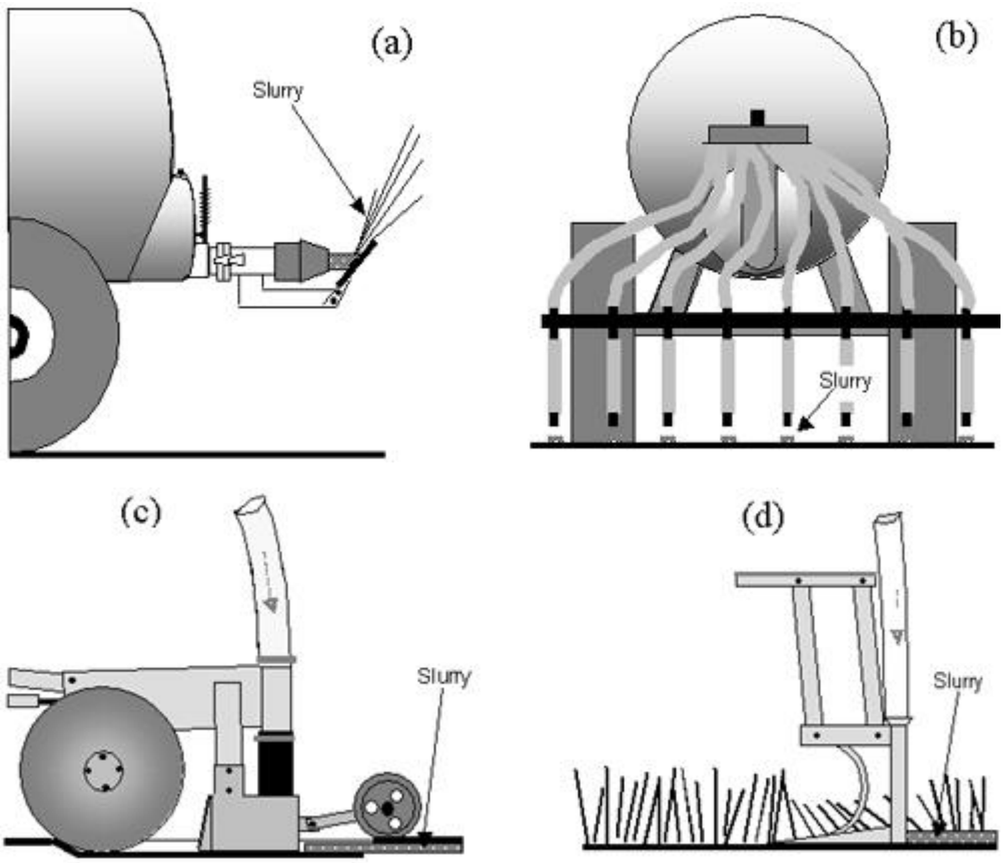


**Fig. 2.5:** Four types of slurry spreader: (a) splash plate spreader; (b) band spreader; (c) shallow injector; (d) TF spreader

### Band spreader

The band spreader uses a distributor to allocate slurry to several outlets placed at 0.4 m spacing along a 6 m boom (Fig. 2.5 (b)). The outlets are flexible and may have a metal tip ending just above the ground. In some machines the flexible hose reaches to the ground and part of the pipe is dragged over the surface.

Band spreaders cause less contamination of grass than splash plate applicators as the slurry is placed in a narrow band. Using multiple outlets allows uniform application. Ammonia emissions are reduced relative to splash plate spreaders due to the smaller contact area between the slurry and the surrounding air (Thompson et al., 1990). Odour is diminished also (Oh et al., 2004). The disadvantages of band spreaders include operational difficulties due to blockages and cost (Ryan, 1999).

### Trailing foot spreader (TF)

The TF spreader is a recent innovation (Huijsmans, 2003). It is similar to the band spreader but it has a shoe at the end of each pipe which parts the crop. It does not penetrate the soil as an injector does Slurry is placed directly on the soil and around the base of the plants (Fig. 2.5 (d)).

### Injector

A slurry injector applicator includes a distributor and multiple outlets. Each outlet supplies an injector assembly at ground level (Fig. 2.5 (c)). This typically includes a disc coulter followed by an injector tine. The latter can be a knife, a chisel, a sweep or a disc. A press wheel is often added behind the injector. The formation of a vertical slot without mixing may promote denitrification but adding wings or a sweep to the base of the injector reduces this effect. The addition of wings can also double the amount of slurry entering the soil at depths down to 160 mm (Pullen *et al*., 2004). Grass yield can be reduced due to dieback along the line of injection. Crop contamination is similar or reduced relative to band spreaders and working width is typically only half that for other spreaders.

Soil resistance to injectors is sensitive to injector design. Tines with a small rake angle minimise resistance. The aspect ratio depth/width for the tine is also important. These two parameters determine whether soil moves upward along the tine causing disruption or downward causing compaction (Pullen *et al*., 2004). Draught force for four injectors under test averaged 650 N per injector at working depth of 6 cm, compared with 39 N for a sliding foot outlet (Huijsmans, 2003)

One injector design uses high pressure (5 – 7 bar) to force a pulsating jet of slurry into the soil without cutting a slot as other injectors do. Damage to the crop is reduced and the draught requirement is low but pumping slurry into the ground at high pressure requires much power from the tractor. During tests with this equipment in the Netherlands only 23% of the $NH_3$ in the slurry was released to the atmosphere (Hol and Huijsmans, 1998).

### Other Methods

On tillage land slurry is normally incorporated during or after spreading. It may be injected or spread on the surface prior to incorporation by plough or fixed tine implement. The emission of odour or $NH_3$ depends on the time lag between spreading and inversion of the soil. Ploughing allows better mixing but the low capacity of this method leads to the fixed-tine cultivator generating lower emissions in most cases (Huijsmans and de Mol, 1999). Direct injection is possible on untilled land and specialised cultivators are available which cultivate the soil and inject the slurry simultaneously.

Slurry can be applied to land by irrigation using a single jet. The jet may be mounted on a tanker or on a separate rig and supplied by pipe. As the slurry is thrown a long distance this method offers the most variable application rates and the highest emission of odour and $NH_3$.

Other methods have been explored in research. Nitric acid was added to slurry to lower its pH and reduce the loss of $NH_3$. Nitrogen from the acid supplemented the N in the slurry. A system was developed to acidify and spread slurry safely in the field (Lenehan *et al*., 1994). A tanker analysed the nutrient content of the slurry and determined the correct application rate in the field. Applications were recorded for inclusion in farm records (Carton and Lenehan, 1997). A band spreader using fluidic diodes (cyclones) at each outlet to limit flow was developed. This achieved a COV for lateral distribution of 10% without the use of a distributor. This approach allows larger pipes to be used so breakdowns due to blockage are reduced without the inclusion of expensive equipment (Scotford *et al.*, 1998).

### Spreader Comparisons

Slurry spreaders differ considerably in their performance. They are compared below on the basis of emission of $NH_3$, odour, uniformity of spread, breakdowns due to obstructions and effect of slurry on grass growth. The portion of $NH_3$ emitted from slurry spreading is 28 % of the total. Low emission spreaders offer the easiest method of reducing emissions. Table 2.4 illustrates the potential.

**Table 2.4: Loss of $NH_3$ in a range of slurry spreading trials reported in the literature**

| | **Ammonia emission (% of splash plate)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Source*** | **a** | **b** | **c** | **d** | **e** | **f** | **g** | **h** |
| **Splash plate** | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| **Band** | | | 61 | 26 | | | | 47 |
| **TF** | | 38 | 57 | | 31 | 20 - 50 | 20 - 50 | 28 |
| **S. Injector** | 12.5 | 15 | 43 | 8 | 15 | | | 48 |

*Source: (a) Phillips *etal.,* (1991), (b) Huijsmans and Monteney, (1999), (c) Smith *etal*., (2000), (d) Huijsmans (2003), (e) Huijsmans *et al*., (1997), (f) van Lent *etal.,* (1993), (g) Shurer (1998), (h) Misselbrook *et al*., (2002)

The splash plate spreader has the highest emission (Table 2.4). Emission after band spreading was only 30 to 60% of that from a splash plate with the TF spreader offering similar benefits. Emissions available from injectors are 10 to 40% of splash plate loss and in a trial with the Direct Ground Injector (DGI) losses were only 23% (Hol and Huijsmans, 1998). Comparison between machines from one source in Table 2.4 is appropriate but comparison between authors is not. Measurements differ between authors and this is due in part at least to different weather, soil and grass condition in trials (Huijsmans, 2003). Ammonia emission data are highly variable with differences between machines sometimes reversed in individual trials. In Phillips *etal.,* (1991) emissions from the injector were significantly lower then from the splash plate spreader. The data of Smith *etal*., (2000) showed significant differences in 5 out of 16 trials, while the differences reported by Huijsmans *etal*., (1997) were significant.

| Table 2.5: Odour emissions measured in trials after slurry spreading. | | | | | |
|---|---|---|---|---|---|
| | Odour concentration after spreading (OU) | | | | |
| **Source*** | **a** | **b** † | **c** | **d** | **e** |
| Splash plate | 59 | 35 | 807 | | 45 |
| Splash Plate + incorporate | | | 65 | | |
| Hose (Band) spreader | | 11 | | 1094 | |
| Hose + disc (incorporation) | | 11 | | | |
| TF | | | 185 | 636 | |
| Shallow injector | 15 | | 173 | 688 | 18 |
| Deep injector | 182 | | | | |

*Source: (a) Phillips *et al*., (1991), (b) Oh *et al*., (2004), (c) Hanna *et al*., (2000), (d) Chen *et al*., (2001), (e) Lenehan, 1987
†This test varies in minor detail from the olfactometer test (Dravnieks, 1980)

Slurry spreading trials are normally conducted outdoors under fluctuating weather conditions. It is difficult to measure odour under these circumstances and literature on the subject is scarce (Table 2.5). At spreading, odour concentrations in the air are high, but they reduce on the spreading day. This was attributed to high winds on the later occasion.

Chen *et al*. (2001) found the band spreader emitted significantly more odour than the TF and the shallow injector. In the other sources, the splash plate appeared to generate more odour than the other spreaders but significant differences were not adequately established. On balance there is evidence to indicate order of odour emission is SP>Bs>TS & I.

Band and TF spreaders make more efficient use of slurry nutrients than splash plate machines. All three sources in Table 2.6 indicate high variability on the part of the splash plate spreader. Frick (1999) found that spreaders with upward and downward facing splash plates, as used in Ireland, had CVs of 35% and 45% respectively. These values would give rise to over-application or to yield reduction in grassland or both.

| Table 2.6 Uniformity of spread (CV% of mean) | | | |
|---|---|---|---|
| **Source*** | **a** | **b** | **c** |
| Splash Plate | 20 | 25 - 27 | 35 - 45 |
| Band spreader | 9.7 | 7 -14 | - |

*Source : (a) Carton and Lenehan (1997), (b) Oh *etal*., (2004), (c) Frick (1999)

If slurry is to be used as a fertilizer it should be spread evenly. The data of Table 2.6 indicate that the CV for slurry spread by the splash plate spreader is at least twice that for the band spreader. The injector and TF spreaders offer similar advantages over the splash plate machine. A CV of about 10% is acceptable for fertilizer spreaders.

In a trial comparing the three slurry spreading methods discussed here, Lorenz and Steffens (1997) concluded the TF spreader gave the best overall performance.

## Slurry pump

Pumps fall into two groups. Vacuum pumps extract air from the top of the tank. Slurry is drawn into the tank but is not allowed to pass through the pump. One or more ball valves are used in the pipeline, before the pump, to prevent this. If properly handled, vacuum pumps give very reliable service. However, they contribute to poor uniformity of spread. Slurry is discharged from the tanker to the field by a combination of positive air pressure from the pump and hydraulic pressure due to the depth of slurry in the tank. The output of the pump is not matched to the flow rate of the slurry so pressure at the slurry outlet varies over time. This contributes to the variability of flow onto the soil.

In contrast, positive displacement pumps, which handle the slurry directly, can provide uniform flow rate at the spreader. For a fixed speed of rotation the rate of output is constant. These pumps may be of rotary piston or screw design but both types are vulnerable to obstacles contained in the manure (Carton and Lenehan, 1997; Sommers and Huijsmans, 1995). Therefore the farmyard should be kept tidy and the slurry as free of obstacles as possible. In addition a chopper filter may be fitted to intercept anything that might damage the pump. Where slurry is to be used as a fertilizer a positive displacement pump is preferred as it improves the uniformity of nutrient application in the direction of travel. A CV of 5% was obtained for longitudinal variation for a tanker using a rotary fixed displacement pump (Carton and Lenehan, 1997). No corresponding information was found for tankers using a vacuum pump. Operating conditions in this equipment are variable and a uniformity test would not be meaningful.

Where a vacuum tanker is used, the application rate can be calculated by identifying the area that should be covered by a given quantity of slurry e.g. one tank-full and endeavouring to discharge that quantity over that area. Using a fixed displacement slurry pump eliminates the need to calibrate application rate. This type of pump discharges a fixed or specific volume of slurry per rotation. Output is determined by shaft speed e.g. speed of the pump shaft. Application rate can be expressed by the following function:

| | |
|---|---|
| Applic. rate (kg $m^{-2}$) = | Shaft speed (rev $s^{-1}$) x Specific volume (kg $rev^{-1}$) |
| | Forward speed (m $s^{-1}$) x Spread width (m) |

Spread width and specific volume are normally fixed. The application rate required can be obtained by setting forward speed and pump speed to the appropriate values.

## Blockage control

The splash plate spreader includes a 50 mm rubber nozzle which easily expands to allow a wide range of obstacles to pass through. Blockages are unusual and where they occur they are easily cleared from the single short pipe feeding the nozzle. Spreaders with distributors are more complex and have a large number of positions where blockages can occur. Obstacles can lodge in the slurry pump, in pipe bends, in the distributor, in outlet nozzles and injectors. The risk of breakdown is greater with these spreaders.

Most obstacles that cause breakdowns during slurry spreading originate in the farmyard. A series of six visits to livestock farms revealed that wood was the worst offender with plastic pipe, stones, silage and plastic sheet among the many other potential obstacles found in slurry (Ryan and Brett, 1999). Tidiness is essential to minimise blockages and agricultural contractors sometimes offer financial inducements to encourage good practice on farms.

Slurry should be homogeneous to allow uniform application of nutrients to the land. During storage, solids settle to the bottom of the pit and in the case of cattle slurry, a crust forms on the top. A range of slurry agitation equipment is available with pump or impeller type mixers. These break up any lumps and mix the solids through the material but potential obstacles often remain. The use of a filter on the intake to the slurry tanker can exclude 90% of the remaining lumps. Filters have worked well in pig slurry which has relatively low viscosity but in cattle slurry agitation for 16 hours or more was required to allow the resistance to flow of a filter to approach that of an open pipe (Ryan and Brett, 1999).

Slurry spreaders using distributors have facilities to reduce breakdowns due to blockage. A chopper filter may be included upstream of the pump to break up any likely obstacles entering the machine. These units normally include a coarse filter with a rotary knife sliding across it or a grill with knives running between the bars. Some have a stone trap for objects that are too big to go through the filter. This equipment is common in the Netherlands where, in a survey of 60 spreaders, 42 were equipped with chopper filters. Most of these tankers had positive displacement piston type pumps which are easily damaged by stones and bits of metal. The remaining tankers used a vacuum pump, the type of pump used most in Ireland, and only one third of these had a chopper filter (Somers and Huijsmans, 1995).

Within the distributor the tops of outlet pipes have sharp edges against which the rotor can break timber or stones. The rotor can be reversed to allow a repeated chopping action. An experimental prototype included a 75 mm outlet in the distributor wall which allowed obstacles to be removed from the distributor. It reduced by 60% the number of obstacles retained in the spreader. This unit is appropriate for use with a vacuum tanker (Ryan and Brett, 1999)

# RESULTS

## Machine selection

The three tankers considered offered similar performance in relation to the key concerns of $NH_3$, odour and nutrient loss to water. The selection sought to identify the machine with the best performance at lowest cost.

The comparison between tankers required the use of a common variable across the field. Finance was used in this study. The main cost (capital cost) was offset by cost benefits in improved grass growth and reduced odour. Ideally a cost/benefit study would yield a positive result for one of the candidate machines but no positive result was obtained here.

An alternative approach allows the observation that the Republic of Ireland is obliged to reduce $NH_3$ emissions by 2010. Trials by both Smith *etal*., (2000) and Misselbrook *et al*., (2002) provided ammonia loss values for all four machines. This allowed calculation of the reduction in capital cost per kg of $NH_3$ that could be achieved using the improved equipment. This cost amounted to €20.5, €17.3, and €23.9 for band, TF and injector tankers respectively where slurry had a low TAN (total $NH_3$ content) of 1.5 kg/t of slurry. At a higher TAN content of 6.4 kg/t, the corresponding costs were €4.8, €4.1, and €5.6. In each case the TF tanker offered the lowest cost per kg of $NH_3$ saved. This tanker appears to be the most economical slurry tanker available to reduce $NH_3$ emissions.

The TF spreader provides most of the benefits of injection. The average ammonia emission of TF spreaders is 60% lower than a splash plate machine. Odour emission is similar to that of the injector. The sliding foot spreader floats over the soil surface causing little if any damage to the sward. Injection can damage the sward. Both spreaders place the slurry under the plants so crop contamination is reduced.

## The proposed tanker

The proposed tanker is illustrated in Fig. 3.1. This consists of a slurry tank with running gear (wheels, brakes, supporting frame and tractor hitch) and lights. It is further equipped with a PTO-powered fixed displacement pump with gear box and a TF spreader. Pipe work is also provided to allow filling at the pump and discharge through the spreader. The fixed displacement pump must be protected from hard obstacles such as metal or stone so a filter is required. This can be a filter attached to the intake pipe and submerged in the slurry or a chopper filter mounted on the tanker. The choice of components is discussed below.

- A sealed slurry tank is chosen to reduce spillage and odour. It does not have positive or negative internal air pressure.
- Wheels, brakes, supporting frame, tractor hitch and lights are necessary to suit field and road conditions.
- The positive displacement pump may be of the screw or rotary piston type and must deliver the same amount of material for each rotation regardless of pump speed or slurry consistency.
- The slurry pump must be protected from obstacles by a filter. This can be a simple intake filter for pig slurry. With cattle slurry the use of this filter will require extended agitation. A chopper filter is the preferred solution where any difficulty is encountered. It can be added to the tanker immediately upstream of the pump. This will handle any slurry so additional agitation, to improve flow properties, is not usually required. Tidiness in the farmyard will reduce breakdowns due to blockages.

The TF spreader provides most of the benefits of injection. The average $NH_3$ emission of TF spreaders is 60% lower than a splash plate machine. Odour emission is similar to that of the injector. The TF spreader floats over the soil surface causing little if any damage to the sward. Injection can damage the sward. Both spreaders place the slurry under the plants so crop contamination is reduced.

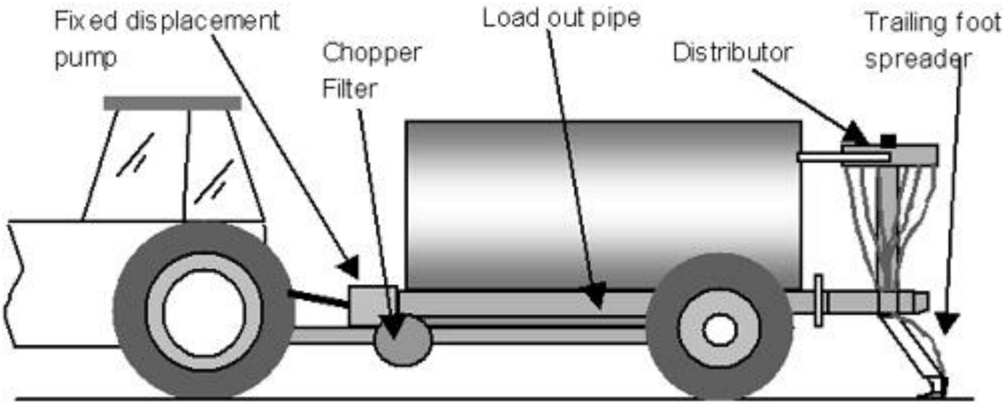


**Fig. 3.1:** The proposed tanker offering reduced emissions and improved spreading precision (chopper filter optional)

Different situations require particular machine facilities. Some of the more common circumstances are described here:

- Pig farm: Slurry on a pig farm tends to be more free-flowing than slurry on other premises. The proposed tanker with intake filter instead of chopper filter might work very well. If odour is a major issue, some form of slurry treatment should be considered to overcome the problem. A shallow injector is unlikely to be better than the sliding TF spreader in this situation.
- Cattle or mixed farm: An intake filter is not appropriate on most farms of this type. It would be wise to include a chopper filter on a tanker working on any farm where cattle slurry is handled. The proposed tanker described above is recommended.
- Contract hire: A contractor's machine should include the components described in Fig 3.1 but the tanker should be larger to increase work rate. It needs to work in many different situations so a chopper filter would be important. Considering the growing interest in nutrient management on farms, contractors might consider offering assistance in this regard. The use of rapid chemical analysis of slurry and recording of application rate using GPS or some other system could provide useful information for farmers. The use of a fixed displacement pump allows application rate to be calculated by, for example, the simple formula given in Section 2.7.

## Machine cost

The cost of owning and operating a machine is determined by many factors. These include cost of manufacture and sale, machine life, interest rate and cost of repairs. The unit operating cost of spreading 1 $m^3$ of slurry can have a wide range of values depending on the value chosen for each variable. The costs reported in Table 3.1 for a splash plate spreader and a TF spreader estimate likely spreading cost (€ $m^{-3}$) over a narrow range of variables.

The two tanker sizes of 3 and 9 $m^3$ in Table 3.1 represent machines used by farmers and contractors respectively. The extra cost of the additional equipment on the TF spreader is estimated at €13,000. This cost is borne more easily by a contractor than by a farmer. Spreader cost is greater than tractor cost because tractors are used for many tasks on the farm but slurry spreaders are dedicated to one operation. Unit costs in this calculation are similar to those calculated by Huijsmans (2003). The largest difference between the two data sets is the cost of the smaller splash plate machine. This is due to a capital cost for the tanker that is 50% higher in the Dutch study than in this analysis and the effect is most visible in the less expensive machine. The same author also gives information regarding cost of spreading slurry in Ireland. This ranges from 3.6 to 6.3 € $m^{-3}$ of slurry spread and is within the range of corresponding values in Table 3.1. Use of an injector instead of a TF spreader would increase costs by 10 to 20% depending on the amount of slurry handled.

The unit cost of operating a slurry spreader can be reduced in several ways. Increasing annual load by using the slurry spreader on more farms spreads the costs over a larger area. Keeping the spreader for periods longer than eight years reduces depreciation charges. Repair costs include housing, insurance and other costs, some of which may not apply on every premises.

**Table 3.1: Estimated cost of operating splash plate spreaders and TF spreaders (2005 values)[1].**

| | Splash Plate[2] | | TF(trailing foot[3]) | |
|---|---|---|---|---|
| **Tanker size ($m^3$)** | 5 | 9 | 5 | 9 |
| **Annual Load ($m^3$ $y^{-1}$)** | 500 | 3000 | 500 | 3000 |
| **Spreader capital cost (€)** | 7063 | 15427 | 20063 | 28427 |
| **Spreader cost (€ $h^{-1}$)** | 53 | 34 | 75 | 32 |
| **Tractor cost (€ $h^{-1}$)** | 15 | 21 | 15 | 21 |
| **Total unit cost (€ $m^{-3}$)** | 5.7 | 2.67 | 14.0 | 4.8 |
| **Nutrient value (€ $m^{-3}$)** | 3.0 | 3.0 | 4.0 | 4.0 |
| | | | | |
| **Alternate unit cost (€ $m^{-3}$)[4]** | 8.8 | 2.9 | 13.6 | 4.1 |

**Notes:** 1. Cost variables: depreciation over 8 years; interest rate 7% $annum^{-1}$; repair cost 11% of purchase price per year and labour 10 € $h^{-1}$.
2. This includes tanker, vacuum pump, splash plate and tractor. Working width is 10 m
3. This includes tanker, chopper filter, FD pump, TF spreader and tractor. Working width is 5 m.
4. Costs from Huijsmans (2003) where labour cost is €14 $h^{-1}$ and tractor costs are included.

While the cost calculation in Table 3.1 is only an illustration of costs that might apply it is evident that replacing splash plate slurry spreaders with more environmentally friendly machines does increase costs. The return in terms of nitrogen saved at €1 $m^{-3}$ (of slurry) does not cover the increased cost of the improved machine. The other benefits in terms of emissions to air and water are as important to society at large as to the farming community.

# DISCUSSION

The ideal spreader for use in Ireland must answer the objectives of reduced emissions to air, satisfy the operational requirements of farmers and be available at reasonable cost. The selection of machines in Section 2 was based on the findings in the preceding review and this approach appears to offer the best option to satisfy these objectives.

It is likely that the proposed tanker will meet the objectives set. Measurement variability in relation to $NH_3$ in air is sufficiently low to allow significant differences to be established. Data are available from several sources which reliably indicate an average reduction relative to splash plate spreaders of 60% for TF spreaders. This converts to a net 17% of the total $NH_3$ emission. It is sufficient to provide the reduction of 8% relative to 1990 levels anticipated in the Gothenberg agreement by 2010 (UNECE, 1999). It may also accommodate some growth in emissions over the 20-year period.

Measurement of odour concentration in the open air is not so reliable. The gases are ephemeral, the concentrations are low and many chemicals are involved. Relatively few measurements are available in the literature and these rarely achieve significance. Even so the trends are clear with the splash plate spreader giving consistently more odour than other machines. The TF achieved scores similar to those of the injector.

The failure to move from a situation where slurry is seen as a waste to one where it is seen as a fertilizer has hindered the management of farm nutrients. As a waste it is disposed of as conveniently as possible. As a fertilizer it should be handled with some care to ensure retention of $NH_3$ and best use of the P and K. The proposed tanker not only allows greater yields but also supports a key environmental objective for agriculture. Spreading slurry in a uniform manner eliminates the need for excess application to eliminate erratic deficiencies. Thus a major cause of excess P in grassland could be reduced or eliminated. This target cannot be achieved without the use of a fixed displacement pump on the slurry spreader.

The number of slurry spreaders in Ireland is 31,000 (CSO, 2000). Using this value with costs from Table 1 it is possible to calculate the cost of replacing all spreaders with improved machines (including tanker, TF, fixed displacement pump and chopper filter). This would be approximately €800m. It would reduce to €400m if spreaders were modified rather than replaced. Either option would achieve the 17% reduction in $NH_3$ emission mentioned above. Many of these spreaders do little work and do not contribute much to the problem of $NH_3$ and odour release. A low return on investment is to be expected from improvements to all of these machines. A more economic outcome could be achieved if only spreaders on medium to large farms and those used by agricultural contractors were improved. The distribution by capacity of machines sold was available in confidence from a manufaturer. This showed that tankers of 10 $m^3$ capacity and larger represent 40 to 50% of working machines and handle over 60% of the slurry. The cost of replacing these machines is estimated at €450m whereas modification costs are not expected to exceed €200m. These tankers handle large quantities of slurry and have the possibility of achieving a substantial reduction in emissions and nutrient loss. A reduction exceeding 10% of $NH_3$ emission can be expected. The need to store slurry for longer periods under the Nitrate Directive will require larger stores and more spreading machines. This expansion in the complement of machinery will facilitate further the introduction of improved equipment.

The possible alternatives to improved slurry spreading do not appear to offer viable solutions at this time. Emissions from livestock housing are difficult to control with the current buildings. Expensive reconstruction would be required to reduce $NH_3$ loss. For this approach to be effective spreading equipment would need to be improved also. Slurry treatment by aerobic or anaerobic process could reduce odour and $NH_3$ loss, but these systems have been available for many years and have not been widely adopted in Ireland.

# CONCLUSIONS

The object of this study is to evaluate splash plate slurry spreaders and to propose improvements that would satisfy farming needs and environmental concerns. The evidence available is presented in the preceding sections. The conclusions to be drawn from this information are listed below.

The overall conclusions from this report include:

- Improved slurry spreading is the best approach to the reduction in $NH_3$ required by the Gothenberg agreement.
- A tanker equipped with TF spreader, fixed displacement pump and optional chopper filter can satisfy the Gothenberg requirement and overcome, to a large degree, the faults of splash plate splash plate spreaders
- The cost of providing this equipment on Irish farms is likely to be between €200m and €800m depending on the options chosen.

Conclusions regarding emission to air are:

- Emission of $NH_3$ from band, TF and injector slurry spreaders is 40, 40 and 20% respectively of that from splash plate machines.
- Anaerobic conditions can develop in an injector slit and this promotes the emission of $NO_2$ and $CH_4$, both of which are green house gases. Emission of these gases is less with other spreaders.
- Odour emission from slurry spreaders is in the order; (splash plate)>(band)> (TF and injector) respectively.

Nutrient management conclusions:

- Band, TF and injection spreaders achieve spreading uniformity of a quality similar to fertilizer spreaders.
- The combination of a vacuum tanker and splash plate provides very uneven application of slurry to the land.
- Uniform spreading allows farmers to rely on P and K applied in slurry when it is applied at recommended rates but the supply of N is less certain.
- Non-uniform spreading often results in over-application of slurry and negative effects for surface water quality. This contravenes obligations under the Water Framework Directive.

Other conclusions:

- TF spreaders place slurry under the crop so crop contamination is reduced.
- Injection spreaders are 10% to 20% more costly than TF spreaders.
- Injectors cut the sod and this can reduce yield.
- The infection rate of humans by pathogens in slurry is low and differences, in this regard, between spreaders are not generally significant. However in particular cases this conclusion might not apply.
- For slurry spreaders with small pipes the number of obstacles in slurry must be reduced in some way.

The introduction of the proposed tanker will incur added costs. However if the UNECE Gothenberg agreement is to be honoured, improvement to slurry tankers are probably the most economic option. In addition, malodours in the countryside would be substantially reduced and farmers would have a means to integrate slurry more effectively into nutrient management plans.

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