COMPARATIVE SURVEY OF MANURE SPREADING TECHNOLOGIES

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Content

Summary

Neighbouring countries Estonia and Latvia have favourable conditions for animal husbandry and farmers on both countries are interested about using best possible ways to handle manure. These benefit also both for farm economy and fulfils legislative requirement. Also, this ensures least ecological load too.

First chapter compares differences and similarities on both countries legislation about manure handling. This knowledge is important for analysing manure handling costs and for planning of activities or investments. Especially, when these activities are performed on both countries by some enterprise. These aspects are also important to consider on legislation analysis or improvement planning, whether by scientists or public authorities. Estonia and Latvia have similarly favourable conditions for animal husbandry and this gives opportunity to compare ecological effect of different requirements. Biggest difference is on P amounts: in Estonia P is limited to 25 kg ha^{-1}, in Latvia such limitation is not present. Therefore is possible to study agriculture-based P cycle in environment.

The choice of manure handling technology is highly dependent on manure properties. On second chapter different manure types are considered. Element prices are calculated to allogeneic manure types. Both economically and ecologically efficient manure handling means delivery of nutrients to plants precisely when needed on amounts necessary. Highly valuable nitrogen is easily volatile as ammonia. This phenomenon is depending heavily on spreading technology, weather conditions etc. Known results about nutrient losses are presented.

Third chapter explains different solid, liquid and semi-liquid spreading technologies more detailed. Machinery prices, pros and cons are considered. Compared are spreading costs on different size farms on various technology choices. Results show clearly, that bigger spread amounts result smaller costs per manure unit. Special transport trailers also reduce transport costs. Service contract is often useful for smaller farms and own work may be more expensive. Bigger farms offer workload big enough for reasonable payback time and therefore equipment resource will be better exploited. Ammonia emission impact on spreading costs is also presented. Trailed hose may lead to high emissions, when weather conditions are favourable to emission and incorporation is done hours after spreading. Emissions from injection or incorporation spreading are less weather-dependant and therefore results better economic and ecological output. Less emission also means less smell.

Fourth chapter overviews present situation on farms now. 60% of manure spread by inquired farms is handled either with injection or incorporation technology. Trailing hose portion was 35% and only 5% broadcasted. 55% of manure was contracted spread and 45% spread by own machinery.

New technologies on manure handling are explained in chapter 5. Acidification is already used on 15% of Danish liquid manure and on some Estonian farms is this technology in use. Interest against this solution is high and on 2016 new three-year project started on this topic, involving countries around Baltic Sea. There are available devices to assess nutrient content of manure during spreading. This makes available precise farming activities, which make possible better nutrient usage efficiency: plants can be fertilized exact amount in precise time according to needs. This helps to reduce leaching too. Separation of semi-liquid manure improves logistics, allowing easier transport for solid and liquid fractions. Proper composting improves solid manure quality and extinguishes pathogens. Promising is technology to use the heat from manure to warm houses or heat water, since both Estonia and Latvia have cold winters.

Chapter 6 is presented recommendations for handling different manure types both economically and ecologically reasonable. There are also some suggestions about changes in legislation and support schemes.

Introduction

Livestock manure is the main source of ammonia nitrogen emissions in the Baltic Sea Region (BSR), which through atmospheric deposition results in airborne eutrophication and accounts for a major portion of the nitrogen entering the Baltic Sea. Ammonia emissions not only threaten the status of the Baltic Sea, but also directly threaten human health through the formation of secondary particulate matter, which is among the pollutants with the highest estimated impact on human health. Including the fact that ammonia emissions from livestock manure also represents the direct economic loss of a valuable agricultural resource. The revised HELCOM Baltic Sea Action Plan (HELCOM Report, 2013) set targets for reducing 118,000 tonnes of nitrogen entering the Baltic Sea, divided among all BSR countries.

Ammonia loss from livestock manure occurs in livestock housing, manure storages and from the field during manure application. Livestock managing apply various Best Available Techniques (BATs) to reduce emissions, such as air purification systems, covers on slurry storages, and injection of liquid manure when spreading etc.…

The overall aim of this project is to identify innovative and economically viable technologies for handling and processing of manure in an environmentally friendly and user-friendly way on livestock farms in the Estonia and Latvia. Bottlenecks and barriers to implementing appropriate available technologies are also examined.
This report presents an overview of manure handling techniques currently being used in practice on animal production farms in Estonia and Latvia.

By using analyses of market and national legislation, the project experts will formulate policy recommendations for integration of the technology in existing legislation and agricultural support schemes.

Expected impacts to the BSR include reduced airborne and runoff caused eutrophication and a more competitive and sustainable farming sector.

1 Estonian and Latvian legislation on manure

Estonia

According to Estonian Water Act (Water Act, 2016) every arable hectare may be fertilised yearly with:

1. up to 170 kg nitrogen, including manure left by pastured animals;
2. up to 25 kg phosphorus, including manure left by pastured animals. Yearly amount can be adjusted so, that on 5-year period average does not exceed 25 kg per ha.

Time for manure spreading

Liquid manure cannot be spread from 1st of December until 20th of March or any other time, when the soil is frozen, covered with snow, periodically flooded or saturated with water	Today in act
Liquid manure cannot be spread from 1st of November until 20th of March or any other time, when the soil is frozen, covered with snow, periodically flooded or saturated with water. Environmental Board can vary spreading brake time start date according to weather and growing conditions from 15th of November.	From 1.1.2023 onwards
Solid and deep litter manure or any other organic fertilizers cannot spread from 1st of December until 20th of March or any other time, when soil is frozen, covered with snow, periodically flooded or saturated with water.	Today in act

Manure should not be spread on areas, where slope exceeds 10 degrees. Areas, where slope is 5–10 degrees, spreading is forbidden between 1st of October until 20th of March.
There is exception possible to fertilize slopes over 10%, when next requirements apply (Ministry of the Environment Ordinance nr 11 “Maapinna kalde määramise alused ning erandid kaldega alade väetamisel”):

1. >10 % slopes constitute less, than 1/3 of field area;
2. >10 % slopes are narrower, than 100 m;
3. Slope area nearest margin must be at least 50 m from doline edge, located downslope;
4. Slope area nearest margin is not bordering water body protecting boundary;
5. Slope area nearest margin is at least 50 m away from open ditch, located downslope;
6. Water collection area upslope located sloped area not bordering protection zone;
7. Slope margin is not bordering service zone of downslope well;
8. Slope area nearest margin must be at least 100 m away from yard, marked on Main Map Layout.

Manure incorportaion on bare soil

The manure spread on bare soil must be incorporated to soil as soon as possible, but not later than in 48 hours.	Today in act
The manure spread on bare soil must be incorporated to soil as soon as possible, but not later than in 24 hours after the finishing of manure spreading.	From 1.1.2021 onwards

Manure spreading on fields with plant coverage

Fields with plant coverage can receive manure during November only, if the manure is incorporated to the soil within 48 h.	Today in act
Solid and deep litter manure can be spread to the fields with overwintering plant coverage until 15.October. Liquid manures must be spread with injector or incorporation into the soil after 20.September.	From 1.1.2021 onwards

Manure storage depending on number of animal

Animal housing for more than 10 animal units (AU) must have suitable manure storage facilities according to manure properties	Today in act
Animal housing for more than 5 animal units (AU) must have suitable manure storage facilities according to manure properties	From 1.1.2023 onwards

Manure storage facilities must accommodate > 8 months manure and, if applicable, also waste water. Pasturing time manure left directly to fields can be deflated from cubage. When manure storage is subcontracted to other enterprise, animal housing must have leak-proof storage facility for one month quantity.

All holding facilities and housing using deep litter technology must be leak-proof and durable to withstand manure handling machinery.

Temporary storing of solid manure depending on number of animals

>10 AU animal sheds must have leak-proof area for solid or deep litter manure temporary storage before spreading or heaping, protected from rainwater	Today in act
>5 AU animal sheds must have leak-proof area for solid or deep litter manure temporary storage before spreading or heaping, protected from rainwater	From 1.1.2023 onwards

Heaping conditions or requirements:

- heaping on arable land is forbidden from 1st of December until 31h of January;
- heap must be on flat area;
- distance to water body, well or karst hole must exceed 50 m;
- heap cannot be made above drainage pipes, uncovered groundwater, over-moist or flooding area.

On arable land is allowed to heap solid manure for two months before application (>=20% dry matter (DM) by amount) in amount used on one growing season. Deep litter manure (DM >=25% by amount) intended for use for one growing season can be heaped for period up to 8 months, if Environmental Board is informed 14 days before heaping.

The manure piles have to be covered with waterproof material or at least 20 cm thick layer of straw, soil, sawdust or wooden chips. If the manure is stored for longer than two weeks, then the storage base should be covered with waterproof material or at least 20 cm thick layer of absorbing material like peat or straw. These requirements do not apply for deep litter manure.

It is not allowed to locate the manure pile on same place for two following years.

A farm, what keeps over 300 animal units and has slurry system, or enterprise, what spreads slurry by contract in amount corresponding to 300 animal units, have to compose a slurry spreading plan before slurry spreading. The plan should contain information on the amount of spread slurry, area for distribution, the spreading method, and the protection level of groundwater, the open surface water bodies and water catchments. Protection level characterizes how fast water infiltrates to groundwater layer from surface. Open surface water bodies are ditches, rivers, lakes etc. These are open. Water catchments are drainage systems and also doline. These lay beneath ground.

The slurry application plan should be approved before application by Environmental Board. The plan is approved for three years. If the slurry amount increases, then the animal owner asks for improvement of existing plan or declares the new application plan. The animal owner has to preserve the slurry application plan for one year after slurry application.

Latvia

According to the Cabinet Regulations No.834 (23.12.2014) „Noteikumi par ūdens un augsnes aizsardzību no lauksaimnieciskās darbības izraisīta piesārņojuma ar nitrātiem" (Regulations for water resources protection from nitrate pollution of agricultural production) every hectare of arable area may be fertilised with manure or digestate yearly with up to 170 kg of nitrogen, including organic manure.

Any fertilizers are not allowed to be spread, when soil is frozen, covered with snow, periodically flooded or saturated with water. In the nitrate vulnerable zones (NVZ) manure is not allowed to be spread from October 20 to March 15, but on grassland from November 5 to March 15.

Nitrogen mineral fertilizer for winter crops are not allowed to be spread from October 5 to March 15, but for others and grassland from September 15 to March 15. The maximum dosage of mineral fertilisers is limited according to yield and crop variety to be spread (for example winter wheat 7 t ha^{-1} – 220 kg N ha^{-1}).

Solid manure spread on bare soil has to be incorporated into soil as soon as possible, within 24 hours, liquid manure within 12 hours. Liquid manure, digestate and slurry can be left on the field without incorporation if used as additional manure in growing crop.

Liquid manure, slurry and digestate should in autumn be spread and incorporated on ground covered with plant residues.

Limitations of spreading manure on slopes:

- it is allowed to spread manure with immediate incorporation in NVZ if inclination is between 5 and 7^0 and the length of slope directed to water source is more than 100 m;
- soil should be cultivated athwart slope and it is allowed to spread manure with immediate incorporation in NVZ or when soil is crop covered if inclination is between 7 and 10^0 and the length of slope directed to water source is more than 100 m;
- it is restricted to spread manure on bare fallow if inclination is more than 7^0;
- it is restricted to spread manure on any field if inclination is more than 10^0;
- if the length of slope is more than 20 m and inclination more than 10^0 it is recommended to keep a vegetation or stubble on.

According to the Cabinet Regulations No.829 (23.12.2014) "Īpašās prasības piesārņojošo darbību veikšanai dzīvnieku novietnēs" (Special requirements for polluting activities in animal houses) requires:

Animal houses with more than 10 animal units (AU) are required to have suitable manure storage facilities according to animal type, production level and housing type. The same applies to the animal houses with more than 5 AU in NVZ.

Manure storage facilities are required to have capacity for storing manure (rain and snow water) for at least 8 months. Pasturing time manure left directly on fields (if applicable) is allowed to be deflated from total capacity. It is allowed to subcontract the exceeding amount to another enterprise.

Liquid manure and slurry storages should either have constructed cover or floating cover for all the storage period.

All storage facilities and deep litter technology housings are required to be leak-proof and durable to withstand manure handling machinery.

It is exceptionally allowed to store solid manure (with DM not lower than 30%) outside the storage no longer than 5 months in a period between May 1 and September 30 or when new storage is built or existing one reconstructed. This storage exception is required to be approved by State Environmental Service. There are some general requirements for this type of storage:

- it has to be made on a field which area is not smaller than to be fertilised the amount of storage in one year;
- it has to be made on flat area (slope not more than 5 degrees);
- the distance to open water body or drinking water well is required to exceed 50 m;
- the distance to drainage dich or drainage well is required to exceed 30 m;
- it has to be protected against leaching.

More details about more specific requirements are available through www.likumi.lv.

Table 1.1. Comparison of manure handling requirements in Estonia and Latvia.

Keyword	Estonia	Latvia
N amount limitations	Up to 170 kg ha^{-1} including pasturing manure N per year.	The amount of N produced in farm (from manure or digestate) should not exceed 170 kg ha^{-1} of arable land per year.
P amount limitations	Up to 25 kg ha^{-1} including pasturing manure P. Amount can be adjusted as 5 year average on tilled area.	No limitations.
Spreading time	Forbidden between 1.12-20.03 and when: • soil is frozen; • snow on fields; • fields are flooded; • soil is saturated with water. From 1.1.2023 onward: forbidden between 1.11-20.03.	Forbidden on arable land in Nitrate Vulnerable Zone (NVZ) between 20.10 and 15.03, on pastures between 5.11 and 15.03. Forbidden on frozen, water saturated or snow covered soil. Allowed on flood plains after floods. Forbidden when: • soil is frozen; • snow on fields; • fields are flooded; • soil is saturated with water. No spreading time limitations outside NVZ.
Water protection zones	1) Baltic Sea, Peipus, Lämmi and Pihkva lake4s – 20 m; 2) Other lakes, water reservoirs, springs, flumes, main ditches and ditches in water collection areas >10 km-2 – 10 m 3) ditches in water collection areas <10 km-2 – 1 m	Forbidden in water protection zones (10 m from shore line) and specially protected zones according to legislation.
Usage of plant nutrients	Amount added mineral fertilizer cannot be more, than necessary to maintain nutrient balance according to soil type, planned yield, crop rotation etc. Over 100 kg ha^{-1} amounts must be divided.	Allowed in NVZ at specific doses for each particular crop according to yield level (for example winter wheat 7 t ha^{-1} – 220 kg N ha^{-1}). See also tables 1.2 and 1.3.
Incorporation on bare soil	As soon as possible (ASAP), within 48 h From 1.1.2021 oward: ASAP, within 24 h.	Solid manure and compost within 24 h, slurry – 12 h.
Inclinations	Forbidden on slopes with inclination >10 degree. Forbidden between 1.10-20.03 on inclinations between 5-10 degrees.	It is allowed to spread manure with immediate incorporation in NVZ if inclination is between 5 and 7 degrees and the length of slope directed to water source is more than 100 m.

	Fertilizer spreading is allowed on slopes >10 % as exception only on areas, where are fulfilled requirements of Ordinance nr 11 from Ministry of the Environment.	Soil should be cultivated athwart slope and it is allowed to spread manure with immediate incorporation or when soil is covered by crops in NVZ if inclination is between 7 and 10 degrees and the length of slope directed to water source is more than 100 m. It is not permitted to spread manure on bare fallow if inclination is more than 7 degrees. It is not permitted to spread manure on any field if inclination is more than 10 degrees and the length of slope directed to water source is more than 100 m. If the length of slope is more than 20 m and inclination is more than 10 degrees it is recommended to keep a vegetation or stubble on.
Fields covered with plants	Between 1.11-30.11 only, when manure will be incorporated to soil within 48 h.	It is allowed to spread slurry and digestate without incorporation if it is intended as additional fertilisation of growing plants.
Wintering plants	Solid manure can be spread only until 15.10. From 1.1.2021 onward: Liquid manure must be after 20.09 injectspread.	It is allowed to spread manure (solid and liquid) and digestate up to 20.10 only if there are plant residues (straw, grassland roots, stubble) on field. This fertiliser has to be incorporated as follows: solid manure and compost within 24 hours, slurry – 12 hours.
Storage availability	Animal housing >10 AU houses must have proper storage according to manure type. From 1.1.2023 onward: >5 AU houses must have proper storage according to manure type.	Animal housing with >10 AU or > 5 AU in NVZ – should store manure in proper storages made of concrete, plastic or metal, securing there is no runoff possibilities. For solid manure slurry should be kept in separate closed tanks. Use of deep litter technology as manure storage is permitted.
Storage capacity	Must hold 8 month manure (and waste water if applicable). Pasturing manure amounts may be subtracted from the storage amounts.	Animal housing with >10 AU or > 5 AU in NVZ should have manure storages with capacity to store manure produced during 8 months. Slurry from solid manure storages should be stored in separate closed containers ensuring storage capacity of 8 months.
Subcontracted cubage	If manure is stored in rented storage, housing must be equipped with a leakage-proof buffer storage, holding at least 1 month amount.	No limitations, but there should be the agreement which should include the amount of contracted manure.
Leaks and safety	Storage facilities must be leak-proof and safe to use.	Animal houses with >10 AU or > 5 AU in NVZ should have storages with base and walls that are leak-proof and can handle machinery.
Solid manure short storage exception	<10 AU house solid manure can be stored temporary (before transport to long-term storage area or spreading) on leak-proof base, protected from rain. From 1.1.2023 onward: <5 AU house solid manure can be stored temporary (before transport to long-term	Deep litter manure with dry matter (DM) of 45 % is allowed to be stored outside not longer than 24 months. All other solid manure may exceptionally be stored on field not longer than 5 months and in the case of reconstruction or repair of storage.

	storage area or spreading) on leak-proof base, protected from rain.	
Solid manure field storage	Solid manure >20 % dry matter content can be stored on field in pile up to 2 months. It must be used within the growing season. Solid manure >25 % dry matter content can be stored on field in piles up to 8 months. It must be used within growing season. Environmental Board must be informed 14 days before piling. The manure pile have to be covered with waterproof material or at least 20 cm thick layer of straw, soil, sawdust or wooden chps. If the manure is stored longer than two weeks, then the storage base should be covered with waterproof material or at least 20 cm thick layer of absorbing material like peat or straw. This is not required ~~by~~ for deep litter manure.	Field storage is allowed only if there is permission of State Environmental Service (SES). DM of manure should be over 30 % and manure should be pileable, ensuring there is no slurry runoff. The amount of manure stored on field should not exceed the amount which is required to fertilise the field for one year. To protect the storage from runoff the base of storage should be made of waterproof material or 30 cm layer of absorbents like sawdust, chopped straw or peat. The absorbent base should be 2 m wider than storage itself. In order to protect the storage from rain and snow also eliminating runoff and evaporation, storage should be covered with 20 cm of absorbent or waterproof material.
Field storage close time	Solid manure field storage is forbidden between 1.12-31.01	No restrictions if there is permit issued by SES. If there is no permission, on-field storage is forbidden between 30.09 and 1.5.
Pile location	Solid manure field storage must be located on flat area. Distance to water body or well must be >50 m. Pile cannot lay above drainage, flooded or uncovered ground water area. It is not allowed to locate the manure pile on same place for two following years.	Field storage of solid manure should be made on flat surface (not more than 5 degree of inclination) at least 50 m from open water sources or drinking water wells and at least 30 m from open drainage dich or any element of drainage systems. Storage on the same place is allowed not earlier than after 3 years.
Solid manure storage exception		Animal houses where animals are kept on deep litter and animal houses for beef cattle, sheep or wild animals, where animals are kept for production purposes outside buildings in fenced area throughout the year are not required to have any additional manure storages.
Solid manure operation documentation	A farm, what keeps over 300 animal units and has slurry system, or enterprise, what spreads slurry by contract in amount corresponding to 300 animal units, have to compose a slurry spreading plan before slurry spreading. The plan should contain information on the amount of spread slurry, area for distribution,	There should be documentation of manure management on farm, registering the amounts produced and used as well as dates of spreading.

	the spreading method, and the protection level of groundwater, the open surface water bodies and water catchments. The slurry application plan should be approved before application by Environmental agency. This is approved for three years. If the slurry amount increases, then the animal owner asks for improvement of existing plan or declares the new application plan. The animal owner have to preserve the slurry application plan one year after slurry application.	

Max allowed amount of N annually depending on crop type and yield level in Latvia

Table 1.2. Crop types/yields and kg ha^{-1} N in Latvia. Balance calculation is based on total nitrogen content

Crop	Crop yield, t ha^{-1}			
	< 3	3 – 5	5 – 7	> 7
Winter wheat	80	120	150	220
Rye	65	95	130	160
Winter barley	75	105	140	185
Winter triticale	75	105	140	200
Spring wheat	80	125	160	200
Spring barley	65	100	135	170
Oats	60	90	120	-

Table 1.3. Other crops/ yield and kg ha^{-1} N

Crop, type of production	Yield, t ha^{-1}	Max allowed amount of N, kg ha^{-1}
Winter rape (seeds)	< 2.0	90
	2.0 – 4.0	150

	4.0 – 5.0 >5.0	190 230
Spring rape (seeds)	< 2.0 2.0 – 3.0 3.0 – 4.0 > 4.0	90 120 160 200
Maize (ensiling crop)	< 40 40 – 60 > 60	110 160 200
Potatoes	< 30 30 – 40 > 40	90 140 180
Fodder beets, sugar beets	< 40 40 – 60 > 60	90 150 190
Cultivated grassland, pastures (hay)	< 4.0 4.0 – 8.0 > 8.0	80 120 170
Pasture (green crop)	< 20 20 – 30 > 30	100 155 240
Cabbage	<45 45 – 70 >70	135 210 240
Carrots	<30 30 – 50 >50	80 130 130
Onions	<25 25 – 45 >45	95 170 200

Beets	<40 40 – 60 >60	110 170 200
Cauliflowers	<20 20 – 40 >40	110 200 240
Cucumbers	<25 25 – 40 >40	100 160 200
Summer squashes, pumpkins	<30 30 – 60 >60	90 185 215
Oil flax		80
Fibre flax		40
Peas, beans, other legumes		40
Fruit trees, berry bushes		130
Strawberries		120
Grassland with more than 50% of clover/legumes		50

NB:
If there is organic matter exceeds 30 % in topsoil of 30 cm, coefficient of 0.7 should be used!

2 Manure Types and their Content of Nutrients

The Regulation no 71 from Estonian Minister of Agriculture (Põllumajandusministri määrus nr 71, 2014) establishes manure classification by content of dry matter (DM):

1. liquid manure or slurry: DM < 8%;
2. semi-liquid manure: DM 8.0–19.9%;
3. solid manure: DM 20.0–24.9%;
4. deep litter manure: DM >=25%.

In Latvia is manure classified by DM:

1. slurry: DM <3%;
2. liquid manure: DM 3-8%;
3. semi-liquid manure: DM 8-15%;
4. solid manure: DM >15%.

Organic fertilisers can be divided as result after pre-storage and storage processes:

1) liquid manure;
2) digestate – it may be separated to liquid and solid fractions;
3) semi-liquid manure;
4) solid manure;
5) seepage, draining from solid manure;
6) deep litter manure;
7) composted manure.

Manure properties are depend on the animal type producing the manure: cattle, pig, poultry *etc.* manure – e.g. pig slurry sediments faster than cattle slurry and therefore it has to be mixed during transportation. Post-storage handling of the manure depends on DM content – can it be pumped (DM until 12%) or shovelled (DM over 12%), and that defines the suitable handling technology.

The overview about nutrient contents of manure produced in Estonia is given in table 2.2. To compare the monetary values of different types of the manure are calculated values by the nutrient content and price Table 2.1. The nutrient prices are calculated by mineral fertiliser prices (Silva-Agro OÜ (http://www.silvaagro.ee/vaetised) [15.02.2016]). WIGOR S price has taken from Baltic Agro pricelist [14.04.2016]. The prices are without VAT.

Table 2.1. The mineral fertilisers used to calculate nutrient element prices.

Element	Fertiliser	Fertiliser price, € t^{-1}	Element content, %	Element price calculation	Element price, € kg^{-1}
N	Ammonium nitrate	268	34.5	268 : 34.5 : 10 =	0.78
K	Potassium Chloride	340	61x0.83=50.6	340 : 50.6 : 10 =	0.67
S	WIGOR S 90	355	90	301 : 90 : 10 =	0.39
P	NPK15-15-15+11S	338	15x0.44=6.6	(338-(0.78x10x15)-(0.67x10x15x0.83)-(0.39x10x11)) : (6.6x10)=	1.43

The sum of products of element content and prices are been calculated to find manure price. For example cattle slurry price by NPK is (2.8×0.78)+(0.5×1.43)+(2.2×0.67)=4.37 € t^{-1}.

Table 2.2. Manure dry matter, NPK, ammonium nitrogen (NH_4^+) contents and monetary value for manure samples analysed by Estonian Agricultural Research Centre. Manure samples are collected from Estonian farms in 2009–2015. Calculations are made according to total nutrient content

Manure type	Number of samples	DM %	N kg t^{-1}	NH_4^+ kg t^{-1}	P kg t^{-1}	K kg t^{-1}	Monetary value, € t^{-1}
Cattle liquid manure	252	5.9	2.8	1.3	0.5	2.2	4.37
Cattle semi-liquid manure	482	14.8	4.2	1.0	0.9	3.1	6.63
Cattle solid manure	140	21.9	5.4	0.7	1.2	4.1	8.67
Cattle deep litter manure	76	30.2	5.9	0.5	1.4	4.8	9.81
Pig liquid manure	146	4.0	3.8	2.6	0.8	1.6	5.17
Pig semi-liquid manure	37	13.4	6.8	3.2	2.3	2.5	10.25
Pig solid manure	8	22.5	7.6	1.8	3.4	4.6	13.86
Pig deep litter manure	13	28.9	7.7	2.0	2.8	4.8	13.21
Hen liquid manure	2	5.4	4.5	2.3	1.5	1.8	6.85
Hen semi-liquid manure	4	13.0	9.0	4.1	3.3	4.6	14.80
Hen solid manure	2	23.5	10.2	4.9	1.9	2.6	12.39
Hen deep litter manure	36	44.3	21.4	5.5	7.4	9.8	33.80
Sheep solid manure	6	21.6	6.8	0.3	1.5	6.3	11.66
Sheep deep litter manure	11	38.4	8.2	0.7	1.8	8.7	14.79

The overview about the dry matter and plant nutrient content in manure produced in Latvia is given in table 2.3. (Lauku kultūraugu mēslošanas normatīvi / Sast. A. Kārkliņš un A. Ruža. Jelgava: LLU, 2013. – 55 lpp.)

Table 2.3. Manure dry matter, NPK contents and monetary value in Latvia

Manure type	DM %	N kg t^{-1}	P kg t^{-1}	K kg t^{-1}	Monetary value, € t^{-1}
Cattle liquid manure	10	4.1	0.6	2.3	5.59
Cattle solid manure	20	5.4	1.1	3.3	7.99
Pig liquid manure	8	3.4	1.0	1.3	4.95
Sheep deep litter manure	25	5.4	1.6	5.8	10.38
Chicken manure (broilers)	55	27.6	5.3	11.5	36.75

The comparisons of annual average nutrients content in slurry samples analysed by Estonian Agricultural Research Centre have shown on figures 2.1 and 2.2. Manure samples were collected from Estonian farms in 2009–2015. We can see on most charts that average nutrient content in manure in 2010 was relatively low and 2012 or 2013 high. It can be assumed that it can relate to economic situation in Estonian farm. In 2009 Estonian farms were in financially poor situation. 2011 was good year for farmers because of high cereal yields and high cereal prices on world market. Thus, if farmers have enough resources to buy additional nutrients for animals and for fodder plants production, then it is reflects also nutrients content in manure. Is this hypothesis true or not, it needs further study.

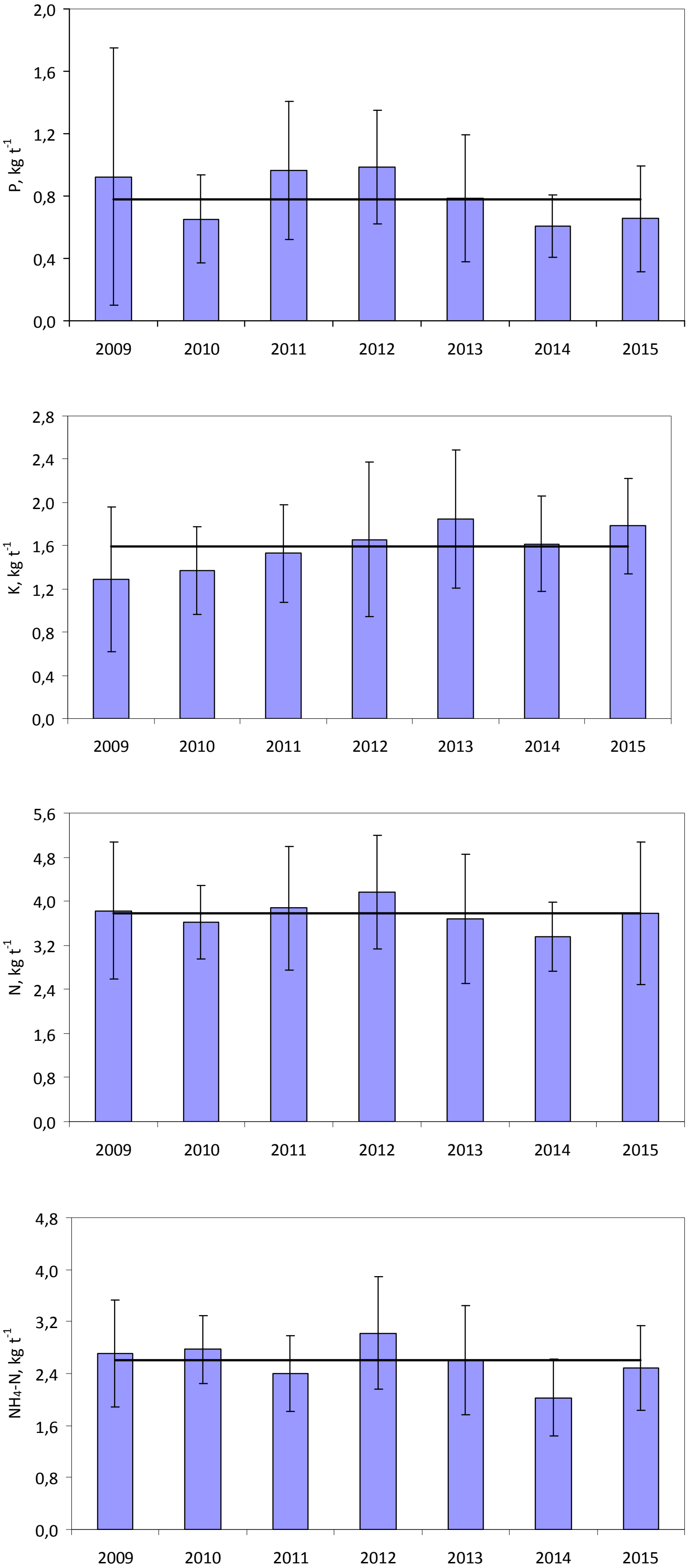

Figure 2.1. The average nutrients content in pig slurry (DM < 8%) samples analysed by Estonian Agricultural Research Centre

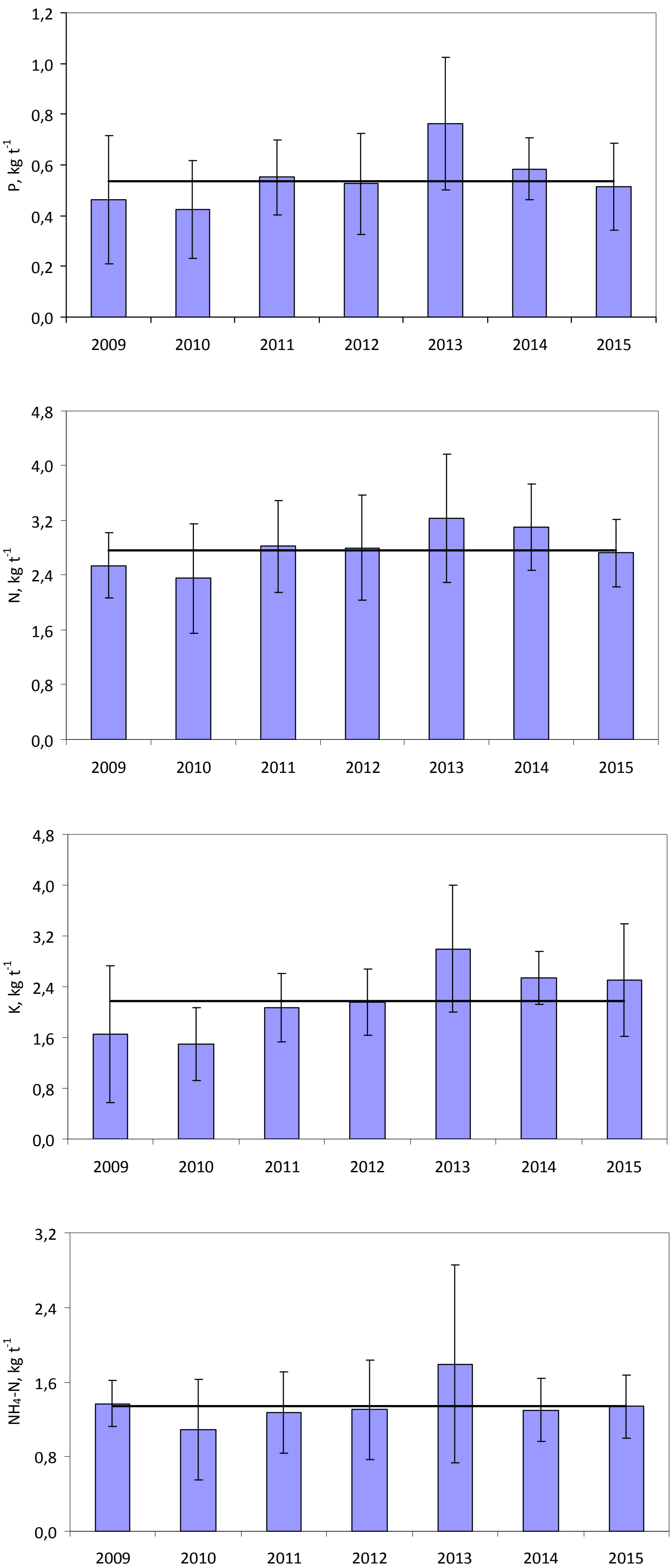

Figure 2.2. The average nutrients content in cattle slurry (DM < 8%) samples analysed by Estonian Agricultural Research Centre

Ammonia emissions from manure

On certain conditions ammonium from manure evaporates as ammonia. This leads to air-inducted euthrophication and reduces manure fertilizing value. Ammonia emissions depending on application technology are shown on Figures 2.3, 2.4 and 2.5. Main factors affecting ammonia evaporation during spreading is shown table 2.4.

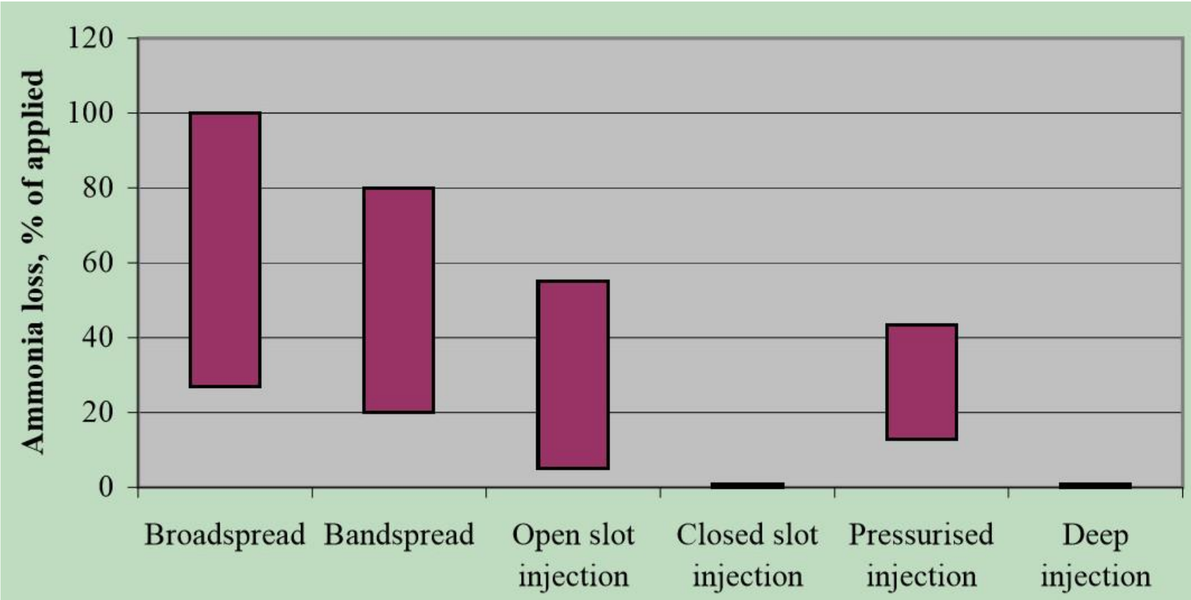

Figure 2.3. Summary of ammonia loss (the percentage of total ammonia nitrogen applied) from field applied manure, using range of application methods. [Bandspread=trailing hose ja trailing shoe] (ALFAM report, 2001).

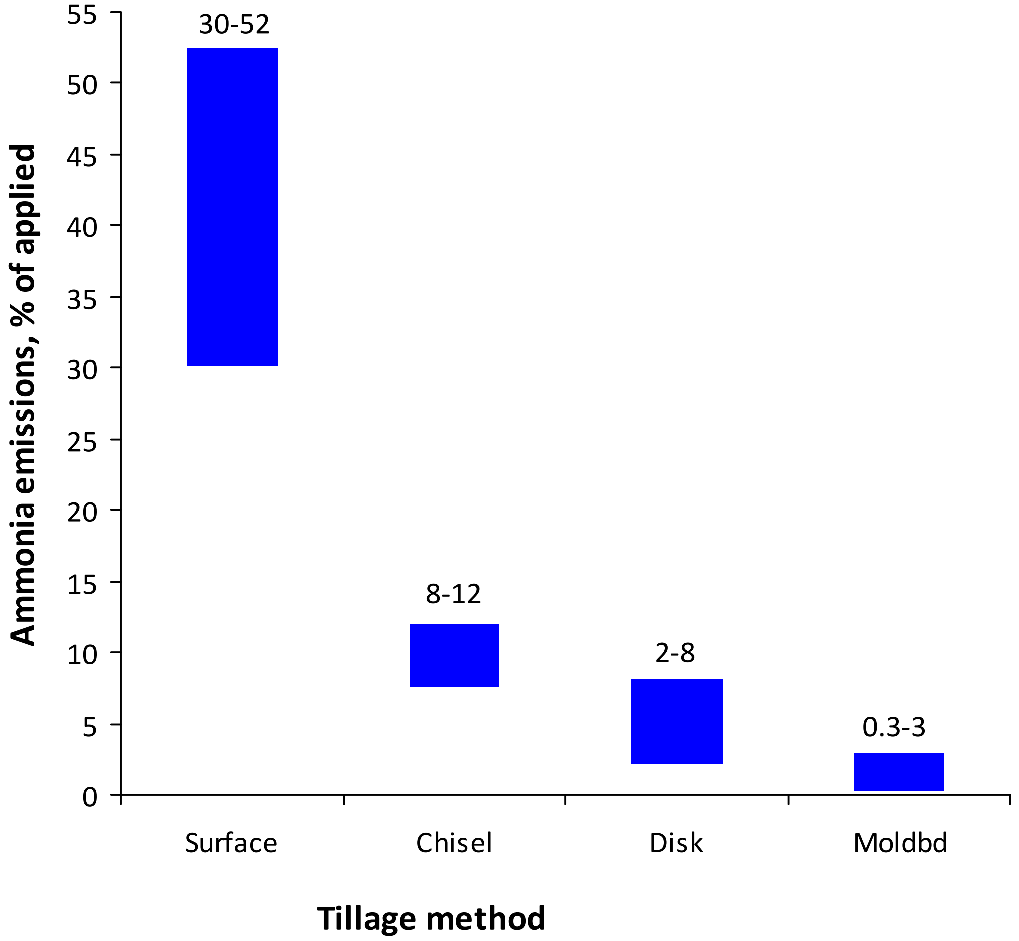

Figure 2.4. Ammonia emission (% of applied amount) by different tillage methods. The slurry was incorporated immediately after spreading. The measurements were done during 5 days. (Thompson & Meisinger, 2002).

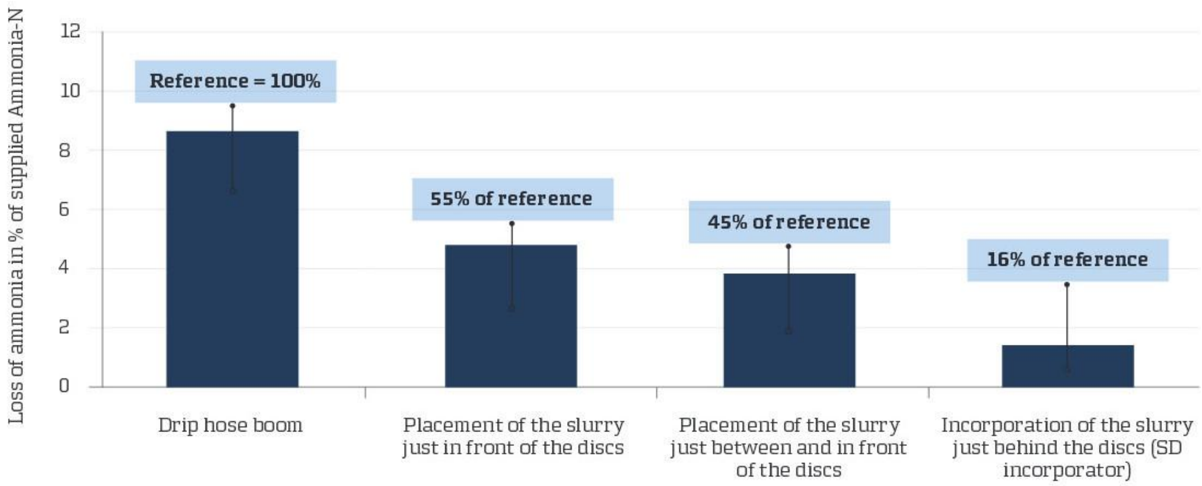

Figure 2.5. Ammonia loss form slurry indicated in % of applied ammonium N. The column represent an average of two experiments with four measurements per treatment. The figures represent the loss of ammonia compared to the loss from the reference drag hose spreading). (http://www.samson-agro.com/media/1814/sd_uk_20151102_hoej.pdf, 2015).

Table 2.4. Factors influencing the emission levels of ammonia into air from spreading (Best Available Techniques, 2015)

Factor	Characteristic	Influence
Soil	pH	Low pH gives lower emissions
	Cation exchange capacity of soil (CEC)	High CEC leads to lower emissions
	Moisture level of soil and porosity	Ambiguous
Climate factor	Temperature	Higher temperature gives higher emissions
	Precipitation	Causes dilution and better infiltration and therefore lower emissions to air, but increased emissions to soil
	Wind speed	Higher speed means higher emissions
Management	Application method	Low emission techniques
	Slurry DM content	The ammonia emission tend to be higher by slurry with higher DM content. Because slurry with more liquid infiltrates faster into the soil.
	Slurry pH	If the slurry pH is under 5 then the ammonia emission is near zero. The higher the pH the more non-emitting ammonium (NH_4^+) is turned to emitting ammonia (NH_3).
	Slurry NH_4-N content	The higher is the ammonium continent in the slurry the higher is the danger for ammonia emissions.
	Time of application	Warm, dry, sunny and windy weather should be avoided
	Dose of application	Excessively high doses increase infiltration periods
Crop conditions	Crop height	Limited ammonia losses when slurry is spread on crops compared to bare land.

The average nitrogen loss due to ammonia emission depending on spreading technology is given in table 2.5 (ALFAM raport, 2001 ja Huijsmans 2003). The influence of temperature and moisture on the ammonium-N loss from manure is given in table 2.6 (AGRI-FACTS, 2008).

Table 2.5. Average ammonium-N loss by different spreading technologies

Spreading technologies	Ammonium-N loss, %
Liquid manure	
Broadcast spreading (no incorporation)	70
Broadcast spreading, incorporation during 12 h	55
Trailing hose spreading (no incorporation)	24
Trailing hose spreading, incorporation during 12 h	10
Trailing hose spreading (height of plants 10–30 cm)	20
Trailing shoe spreading (height of plants >8 cm)	18
Open-slot injection (grassland)	10
Incorporation spreading	5
Closed-slot injection (grassland)	1
Closed-slot injection (arable land)	1
Solid manure	
Broadcast spreading, incorporation immediately	15
Broadcast spreading, incorporation after 4 hours	30
Broadcast spreading, incorporation after 24 hours	50
Broadcast spreading, no incorporation	60

Table 2.6. Estimated loss (%) of the ammonium-N due to weather and soil condition

Time between spreading and incorporation	Average	Cool (< 10 °C)		Warm (>25 °C)	
		Wet	Dry	Wet	Dry
1 day	25	10	15	25	50
2 days	30	13	19	31	57
3 days	35	15	22	38	65
4 days	40	17	26	44	73
5 days	45	20	30	50	80
Not incorporated	65	40	50	75	95

Researcher Peter Viil from Estonian Crop Research Institute has made trial to identify the impact of time between slurry spreading and incorporation on the yields of cereals. In the table 2.7. is presented results of four replications.

Table 2.7. The impact of time between cattle slurry trailed hose spreading and incorporation to spring wheat Hewilla yield in 2009.

Time between spreading and incorporation, h	Yeld t ha^{-1}, average of four replications
0	6.13
2	5.17
4	5.04
6	4.29
10	3.71
20	3.49
30	3.33
40	3.31
48	3.31

3 Manure Application Technologies, Machines and Economy

3.1 Application technologies and equipment for solid manure

Solid manure can be handled mainly by two different technological variants: with direct or pre-haulage. Direct haulage is used if distance between storage is short. It is estimated that it usually does not exceed 3 km. However, it depends on local conditions and may be different. The technological order by of direct haulage is:

1) storage;
2) loading from storage to the spreader;
3) transport from storage to the field with spreader;
4) spreading to the field.

If the field is located farther from the field and the farmer hasn't enough manure spreaders, then it's rational to use pre-haulage technology. It's troublesome to load the solid manure from transporter to the spreader and therefore the manure is disposed to the heap on the field. Often the manure is piled to the fields when there is best time for haulage and the application is made on another, more suitable moment. Technological order by pre-haulage is:

1) storage;
2) loading from storage to the transporter;
3) transport from storage to the field with transporter;
4) piling to the field;
5) storage in the field heap;
6) loading form heap to the spreader;
7) spreading to the field.

When the choosing of the technology it should be kept in mind that buffering on the field helps to minimize transportation time in the urgent field application period. However on the other side the on-field loading (from heap to the loader) costs are saved if direct haulage is used. Also the legislative limitation and significant loss of nutrients should be considered if the on-field piling is used.

Spreaders for solid manure are divided by several characteristics:

1) coupling - trailed, mounted or semi-trailed spreaders;
2) spreading direction - rear or side spreading;
3) feeding system – conveyor or pushing plate;
4) spreading systems – beaters, discs, flails, or rotors;
5) beaters positions – vertical, horizontal or longitudinal;
6) beaters construction – teeth, auger, paddle or flail;
7) number of beaters- 1, 2, 3, 4…;
8) container - box or bin;
9) trailed spreaders are divided by number of axes 2- or 3-axes;
10) semi-trailed spreaders are divided to axes 1- or tandem-axes.

Generally, the solid manure spreaders are semi-trailed and consist following devices: chassis, container, feeding system, spreading system, drive, hydraulic- and electrical devices.

Mostly rear spreading beater spreaders with box are used (Figure 3.1, 3.2, 3.3, 3.4, and 3.5).

Beaters are driven by chain transmission which is equipped with safety coupling to avoid excessive load. The chain transmission is driven by hydraulic engine or PTO.

Figure 3.1. Rear spreader with horizontal beaters (Pronar, 2016)

The prices of spreaders with horizontal beaters are between 10 600–38 000 € (Table 3.1). The machine prices used in this report are taken from Estonian machinery catalogue. All prices are without VAT.

Table 3.1. The prices of spreaders with horizontal beaters

Box volume, l	Number of spreaders in catalogue	Price, €		
		average	min	max
4 100-6 000	3	13 500	10 600	12 300
8 000–10 500	4	20 600	14 000	27 000
12 000	2	36 500	35 000	38 000

The prices of spreaders with vertical beaters are between 8 800–68 000 € (Table 3.2).

Table 3.2. The prices of spreaders with vertical beaters

Box volume, l	Number of spreaders in catalogue	Price, €		
		average	min	max
5 600–7 900	9	15 100	8 800	27 200
8 000–10 300	15	22 000	10 000	38 000
10 500-13 000	15	26 800	13 500	41 000
13 200–15 900	11	35 800	13 700	54 000

16 000–19 000	6	40 300	29 300	58 000
23 000–26 000	3	55 800	34 100	68 000

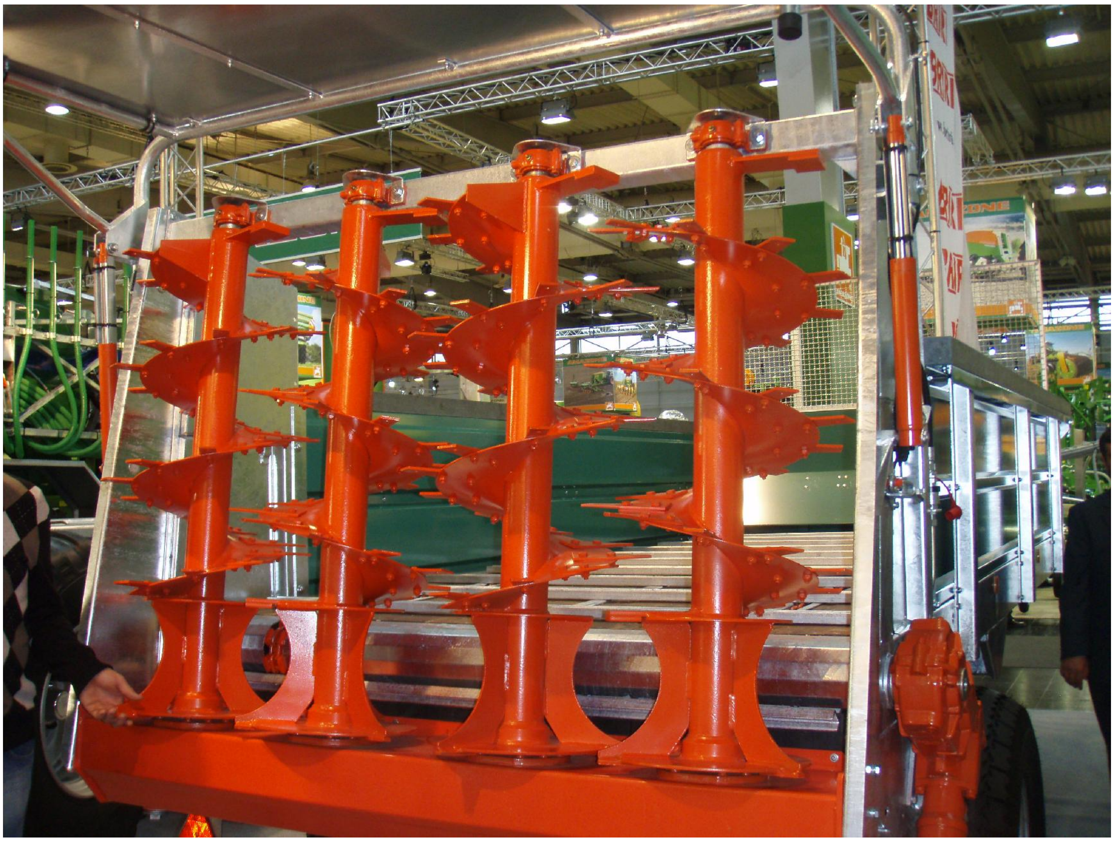

Figure 3.2. Rear spreader with 4 vertical beaters (Photo: R. Vettik)

Figure 3.3. Rear spreader with 2 vertical beaters and discs (Photo: R. Vettik)

The prices of spreaders with vertical beaters and discs are between 14 500–75 300 € (table 3.3).

Table 3.3. The prices of spreaders with vertical beaters and discs

Box volume, l	Number of spreaders in catalogue	Price, €		
		average	min	max
7 500–9 500	3	21 300	14 500	26 500
10 000–12 800	9	28 100	23 700	31 600
13 000–15 900	10	33 700	15 700	59 000
16 500–19 000	9	34 100	23 100	41 000
20 000–22 000	6	40 500	28 000	47 000
23 000–24 000	5	53 800	37 600	68 900
26 000–35 000	4	54 900	31 600	75 300


Figure 3.4. Rear spreader with horizontal beaters and discs (LMR, 2016)

The prices of spreaders with horizontal beaters and discs are between 25 950–115 000 € (Table 3.4).

Table 3.4. The prices of spreaders with horizontal beaters and discs

Box volume, l	Number of spreaders in catalogue	Price, €		
		average	min	max
7 000–10 500	6	28 300	26 000	36 000
11 000–13 500	7	33 600	18 000	44 000
14 000–17 500	9	51 200	24 600	80 000
19 000–22 000	8	62 100	29 100	87 000
22 500–28 000	6	73 300	38 700	115 000


Figure 3.5. Rear spreader with flail beaters and discs (HiSpec, 2016a)

Side spreader has a rotator with paddles (Figure 3.6), spearing disc (Figure 3.7) or longitudinal beater with flails (Figure 3.8).

Figure 3.6. Side spreader with rotator (Kirchner, 2016)

Figure 3.7. Side spreader with spreading disc on side (Photo: R. Vettik)

Figure 3.8. Side spreader with longitudinal beater and flails (HiSpec, 2016b)

Solid manure dosage calculation

Manure dosage per hectare depends on distribution speed, unloading capacity of the spreader and spreading width.

The driving speed what is needed for certain dosage rate, is calculated with formula

$$v = \frac{36Q}{b\,p},$$

where Q is unloading performance of spreading device(kg s^{-1}), p is manure rate per hectare (t ha^{-1}) and b is working width of spreader (m).

The unloading performance can be measured by time used to unload some amount of manure from the spreader box. The easiest way to do it is to weight spreader with some amount of manure, unload the box during measured number of seconds (e.g 60 s) and weight spreader again. The difference of weights (kg) is divided by the number of seconds and the result is unloading performance.

For example if the distribution rate is 25 t ha^{-1} , working width 4 m and unloading capacity is 27 kg s^{-1}, then the required driving speed is
(36x27):(4x25)=9.7 km h^{-1}.

The summary about solid manure spreaders

- Horizontal beater spreader is appropriate for spreading of solid manure and can also spread compost. Overflow or flail beater spreaders can tolerate stones in the ground surface etc. well. The spreading width is about same as the width of the spreading device. There is a risk that too big manure pieces (from deep litter manure) are thrown on the field and therefore the distribution of nutrients is uneven and the big pieces can jam following tillage tool.
- Vertical beater spreader is suitable for solid manure spreading and can also spread compost. Vertical beaters are more suitable for spreading of deep litter manure because the manure layers are crushed by beaters before spreading and nutrient distribution is improved compered to horizontal beater spreader. The distribution width is wider than for the horizontal spreader.
- Tight box and rear gate makes possible to spread semi-liquid manure or solid material consisting mainly small pieces like compost or wood ash.
- The spreading discs under beaters help to achieve wider spreading width and improve the evenness of the nutrient distribution on the field.
- Sidespreaders can spread nearly anything, but working quality depends on uniformity of manure and percentage of straw/hay stems. Materials with high stem content can be spread evenly only with sidespreaders equipped with a shredding apparatus.

Weather conditions (see Table 2.6) and the time span between manure spreading and incorporation have high impact to the ammonia emission from manure. The data about ammonia emission during solid manure spreading are given in table 2.5. Therefore is suggestable to spread manure in suitable weather conditions and incorporate the manure immediately after spreading.

Humid, windless, cloudy and cool weather is favourable for manure spreading. However, the soil must not be frozen, covered with snow nor over-flooded. Also spreading during heavy rain must be avoided, because of the manure run-off risk.

3.2 Slurry Application Equipment

3.2.1 Overview about technologies

The transportation, application and incorporation of slurry can be made with direct technology (same machine is transporting and spreading) or with pre-haulage technology (different machines are used for slurry transportation and spreading).

The trailed, semi-trailed or self-propelling spreaders are used to transport and apply slurry to the fields near to the storage. For longer distances the trucks with tank volume up to 30 m^3 are used to transport the slurry faster to the fields (Figure 3.9). The weight of vehicles is limited with legislation and bearing capacity of roads. By Estonian legislation the maximum weight of vehicles is limited with 40 t and the weight per axle depending on construction of chassis is up to 11.5 t. Plus, the local municipalities are allowed to establish additional limits to the weight per axle. Often this is used in spring when the total weight is limited to 8 tons because of risk of decomposing of roads.

In Latvia are limits for maximum weights following:

Type of vehicle	Parameter name and value
	Maximum weight, t
2 axle trailer	18
3 axle trailer	24
2 axle truck plus 2 axle trailer	36
2 axle truck plus 3 axle trailer	40
tractor plus 2 trailers	40
	Maximum axle load, t
2 axle trailer	20
3 axle trailer	24
	Maximum length, m
Trailer	12
Truck plus semitrailer	16.5
Truck plus trailer	18.75
Tractor plus 2 trailers	18.75
	Max width. m
All vehicles	2.55

To avoid idle times of transporters and spreaders, the mobile buffer tanks are used on the fields (Figures 3.10 and 3.11). The breaks are result of differences between volumes of transporter and spreader tanks and different durations for loading of transporter tank and unloading of spreader tank. The volume of the buffer tank should be at least same as transporter tank volume and spreader tank volume, because then the transporter and spreader can work independent from each other. To load the slurry from buffer tank or transporter tank to the spreader tank, the spreader pump is used (Figure 3.12), though another solution is to use a pump driven by separate tractor (Figure 3.13).

Figure 3.9. The tank truck for slurry transportation is loaded by storage (Photo: K. Tamm)


Figure 3.10. The buffer tank fabricated from freight container (Photo: R. Vettik)


Figure 3.11. The buffer tank with dismountable pump. On the background – trailed hose spreader is in transportation position and pumps slurry from buffer tank to the spreader tank. The hose in the foreground is used to pump slurry from truck tank to the buffer tank. (Photo: R. Vettik)

Figure 3.12. The pump of the self-propelling spreader is used to fill spreader tank (Photo: K. Tamm)


Figure 3.13. The pump mounted on a separate tractor is used to fill spreader tank (Photo: R. Vettik)

The alternative to the vehicles is to use pipelines to pump the slurry from storage to the fields (Figure 3.14). The slurry is pumped continuously from the storage or buffer tank along the pipeline to the spreader working on the field. For pipeline 90 or 160 mm hoses are used. The spreader has no tank and it trails some hundred meters long pipeline after itself during spreading. The pipeline is often transferable and if the distance is over 4 km, an extra pump is used. Also stationary pipelines are used to transport slurry up to 8 km-s. If distances are longer, then vehicles are used to transport the slurry to the buffer tanks, from which the slurry is pumped along the hose to the spreader.

The advantage of pipelines is less soil compaction; the drawback is the need to have level field surface to ensure smooth moving for hose. On the fields near to the storage it is possible to achieve big spreading capacity. This method is not recommended for small separate fields, because after every field the hose should be drained and coiled for transportation. The hose drums are mounted on separate trailer or spreader which can be mounted (Figure 3.15), semi-trailed (Figure 3.16) or self-propelling (Figure 3.17). If the mounted spreader is used, then it is common that the tractor has hose drum on front hitch and after slurry application the hose is coiled on the drum to move to the next field. Semi-trailed and self-propelling spreaders have usually a bigger drum which is used to coil and reel off the hose during work movements on the field. The dry matter content of slurry should be under 5% to avoid jams (Vacutec, 2011).

Figure 3.14. The pump used to feed pipe line with slurry (Agrometer, 2016a)

Figure 3.15. Umbilical spreader mounted on the tractor (Vacutec, 2016)

Figure 3.16. Trailed umbilical spreader (Veenhuis, 2016)


Figure 3.17. Self-propelling umbilical spreader (Agrometer, 2016b)

3.2.2 Slurry spreaders

The classification of tank trailers used for slurry distribution is following.
By method of loading and unloading:

1) a pump on tank is used for slurry pumping;
2) a compressor is used to produce under- or overpressure of air in tank and due to that the slurry is sucked into the tank or pushed out from the tank.

By number of tank trailer axles:

1) single axle trailers;
2) two-axle trailers;
3) tri-axle trailers.

By tank material:

1) plastic;
2) fiberglass or
3) steel.

Slurry spreader consists of:

1) chassis; steel tanks can be without extra frame and thus the tank itself is the element connecting and carrying another devices and systems;
2) slurry tank which can be from hot zinced steel or inside laminated with epoxy resin to make the steel tank resistant to corrosion, aluminum or plastic tanks are also in use;
3) pump, which can be compressor-vacuum, centrifugal, rotary vane, lobe or eccentric spiral pump;
4) distributor with horizontal or vertical rotor (usually provided with macerator) or auger conveyor to distribute the slurry to the hoses;
5) spreader – broadcast spreader, trailed hose spreader, open-slot injector, closed slot injector, incorporator, strip-till spreader.

The pump tanks have volumes between 6 000–30 000 l and prices between 8 800–225 800 € (table 3.5) and vacuum tanks have volumes between 3 000–30 000 l and prices between 5 700–252 000 € (table 3.6).

Table 3.5. Average prices of the pump tanks

Tank volume, l	No of devices	Price, €		
		average	min	max
6 000	6	12 900	8 800	15 100
8 000	7	19 500	15 800	31 000
10 000	7	32 800	11 740	83 900
12 000	7	38 500	25 500	75 800
15 000	20	54 400	20 200	139 000
18 000	13	62 200	38 000	132 000
20 000	6	96 800	26 430	144 900
24 000	8	145 400	47 500	171 500
30 000	5	163 500	51 800	225 800

Table 3.6. Average prices of the vacuum tanks

Tank volume, l	No of devices	Price, €		
		average	min	max
3 000	4	5 900	5 700	7 300
5 000	4	9 500	7 600	10 400
7 000	6	13 700	9 400	25 400
8 000	14	19 200	11 900	57 000
10 000	15	30 000	13 600	62 300
12 000	12	37 000	19 500	64 300
16 000	18	50 500	22 700	87 000
18 000	13	58 900	27 500	117 000
20 000	7	61 400	35 200	118 800
24 000	12	99 500	41 400	146 800
30 000	4	124 500	56 800	252 000

The slurry application can be divided to broadcast and band spreading. The versions are following:

- spreading on the surface;
- spreading on the surface with simultaneous incorporation;
- injection into the soil.

There are two ways to spread on the surface: broadcast spreading where the slurry is thrown through the air to the field surface (Figure 3.20), and band spreading where the slurry is divided through the trail hoses on field surface as bands (Figure 3.23).

The location of the slurry in the plough layer intersection in the case of different application technologies is shown on Figure 3.18. We can see from figure that if broadcast spreading is used (A) then the surface, where the ammonia can emit from, is biggest. If incorporation application is used (C) then the slurry is mixed with soil and ammonia emission is inhibited.

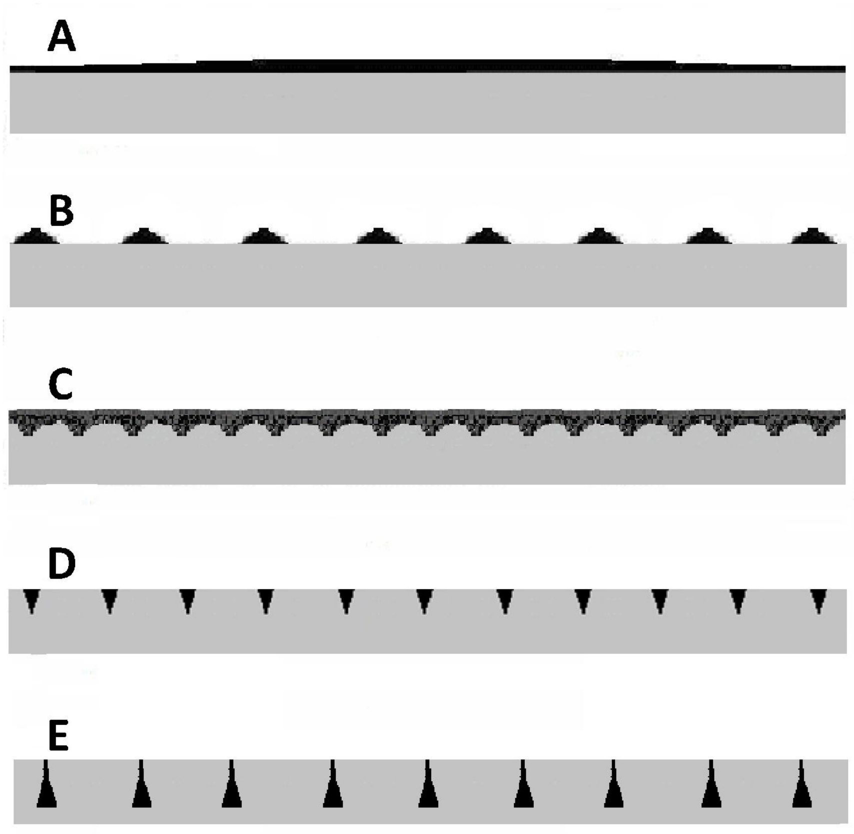

Figure 3.18. The location of the slurry in the plough layer intersection in the case of different application technologies (A-broadcast spreading, B-trailing hose spreading, C-incorporation spreading, D-open-slot injection, E-closed-slot injection)

3.2.3 Broadcast spreaders

The broadcast spreaders consist of the slurry tank trailed by the tractor and also the distribution device. There are various distribution devices in use, however the most simple has nozzle and splash plate (Figure 3.19) directing the slurry jet through the air to the field amplifying the ammonia emission in this way (Figure 3.20).

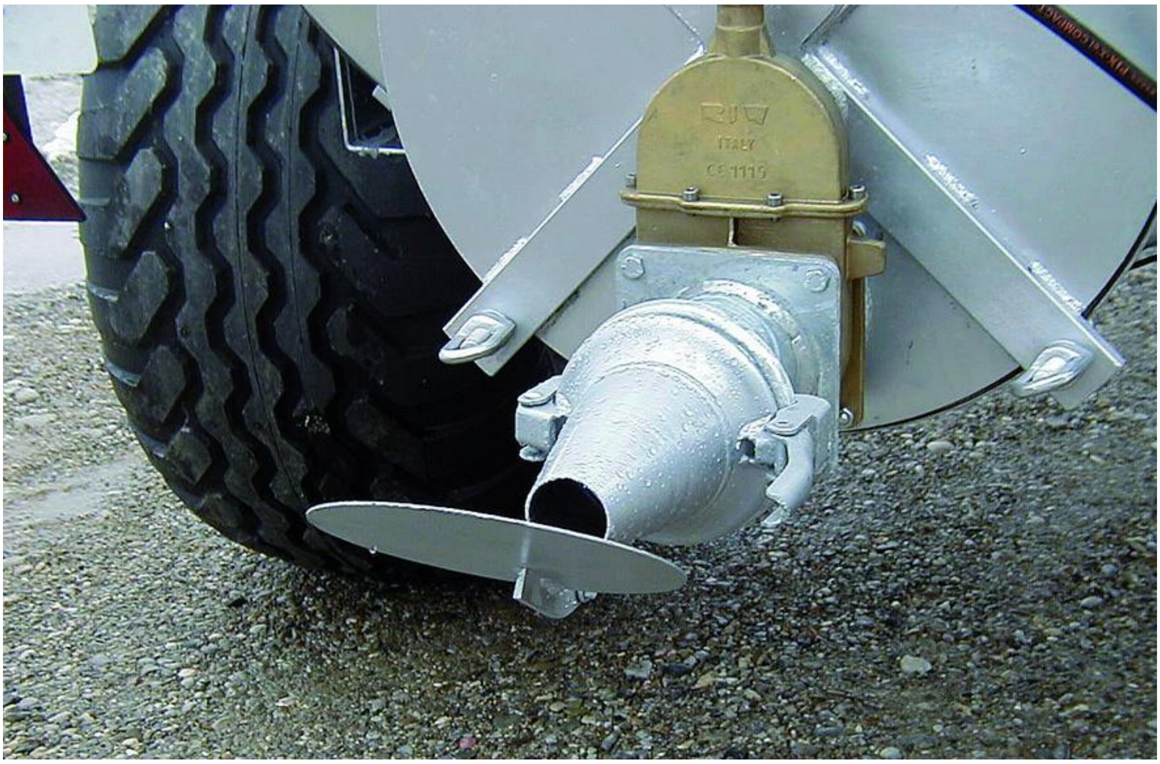

Figure 3.19. Broadcast distributor with splash plate (Fliegl, 2016a)

The spreaders with more complex construction achieve better distribution uniformity. For broadcast spreading with distribution device with adjustable throwing direction are used mechanically or electrically swayable nozzles or plates which allow to aim slurry at both sides (Figure 3.21a). The pendulum nozzle ensures lower distribution fan (has the shape like a hand fan) to achieve better cross-directional uniformity. An upright device for slurry directing is used to produce a vertical distribution fan directed from up to down to minimize up-throwing of emitting gasses (Figure 3.21b). The distribution devices with upper position or several distribution devices are used to get bigger spreading width (Figure 3.22). If several distribution devices are used, then they are positioned lower, and on the boom to minimize slurry distance to the field, and therefore the emission of gaseous compounds.
The ammonia emission is significant if broadcast spreading is used. If there is no incorporation into the soil then up to 70% of ammonia can emit. If slurry is incorporated into to the soil 12 h after spreading, then up to 55% ammonia can emit – thus the incorporation should be done immediately after spreading. In addition to the ammonia emission there is remarkable odour issue, which can be problem if application is made to the fields near to the settlements or public roads. The plants are contaminated if grassland is fertilised with broadcast slurry distributor. Compared to other type of spreading technologies, the broadcast spreading is more vulnerable by wind, and there is unevenness on the field ends because of fan-shaped distribution. If there is raining on spreading time or after that, then risk of run-off is high on slopes.

The advantage of broadcast spreader is that this is cheap, changing from work to transportation mode is not time consuming, the spreader is well suitable for slurry transportation and thus for distribution with direct haulage technology on distant fields. The broadcast spreader is suitable to distribute slurry on cereal fields with chopped straw on calm and foggy days. However, the slurry should be incorporated immediately anyway. The price of the broadcast distribution device (without tank) is between 500–1 000 €.

Figure 3.20. The ammonia emission is higher if broadcast spreading is used compared to other slurry spreading technologies. (Photo: P. Viil)

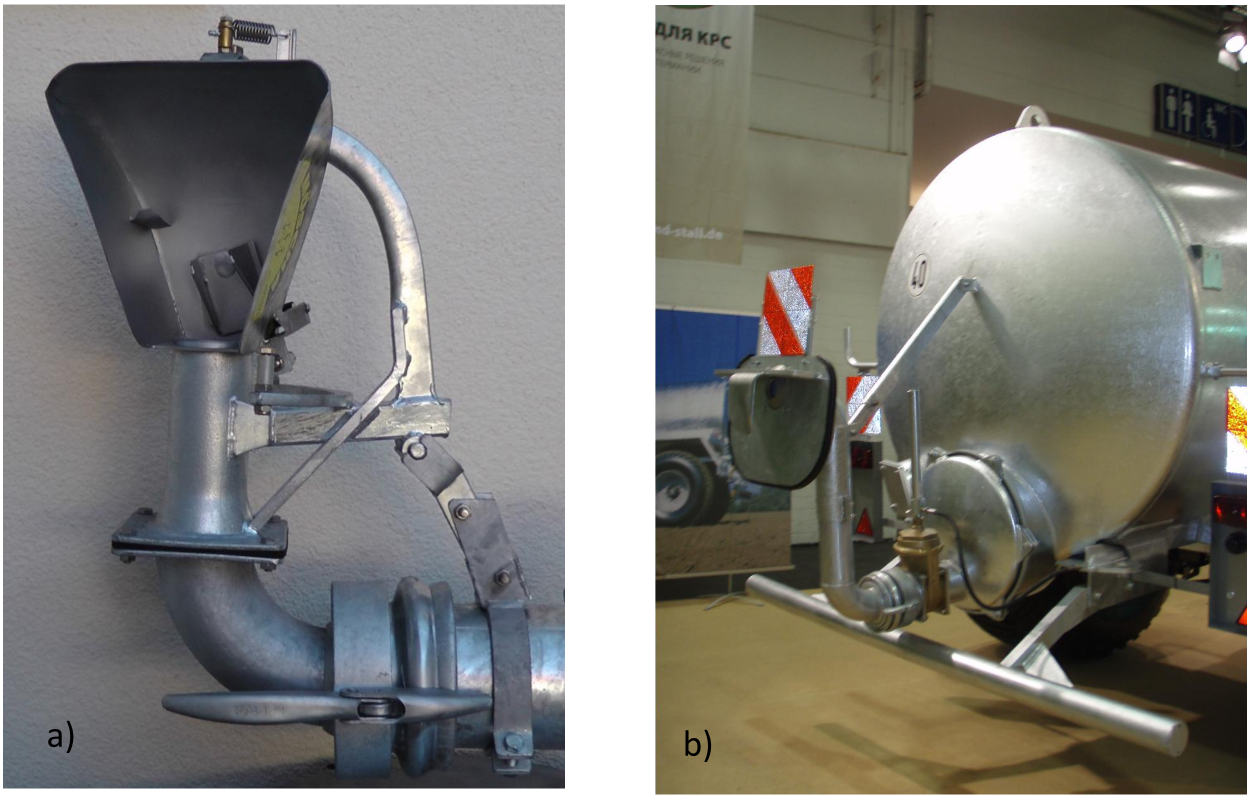

Figure 3.21. Broadcast distribution device which enables to adjust spreading direction (a) (Möscha, 2016) and an upright device for slurry directing from up to down (b) (Photo: R. Vettik)

Figure 3.22. Several splash plates are set on a boom (Photo: R. Vettik)

Advantages. Broadcast spreaders are cheaper and lighter to transport than other spreading devices. The simpler device are in range 500–1 000 € without tank, the need for power is smaller and spreading capacity is high.

Disadvantages. The ammonia emission is so high that this is not considered to be BAT. The slurry has to be incorporated ASAP to minimize ammonia emission. Uneven distribution. The trailing hose spreading requires separate operation for slurry incorporation.

3.2.4 Trailing Hose Spreaders

Trailing hose spreaders consist of slurry tank, distributor and hoses. The trailing hose spreader can be classified by the spreading device:

1) trailing hose spreading device with hoses mounted on a boom, but which haven't any equipment to push plant leaves aside;
2) trailing nozzle spreaders with shoes mounted on the boom and connected with hoses. Shoes are pushing plant leaves aside enabling the following nozzles to make slurry stripes on surface between plants. It helps to minimize the contamination of plants with slurry.

Trailing hose spreader hoses are mounted on the boom with equal distance (20–30 cm) (Figure 3.23). Mostly used work width is for trailing hose spreaders 12 m. Maximum width is 36 m, then there are more than one slurry distributor on the spreader. Due to surface-near spreading is ammonia emission lower than by broadcast spreading. By trailing hose spreading the ammonia emissions may reach up to 24% if not incorporated. If incorporation is made 12 h after spreading, then the emissions are up to 10%. It is recommended to fertilise plants which are higher than 8 cm because then the wind near the ground is weaker than when the plants are smaller. Like broadcast spreading, the trailing hose spreading has remarkable odour issue and risk of surface run-off.

Figure 3.23. Rear look on trailing hose distributor (Photo: R. Vettik)

The distribution method is suitable for fertilisation of arable lands and grasslands as well for fertilisation of cereals and rapeseed during the growing time. The risk that slurry contaminates the plants should be considered if the grasslands are planned to be used for silage or pasture. Due to big width of the device it is hard to use it on small, irregular plots with steep slopes. Width of spreaders is between 6–36 m and prices between 10 500–12 8300 € (Table 3.7).

Table 3.7. Working widths and prices of trailing hose spreaders

Working width, m	No of devices in catalogue	Price, €		
		average	min	max
6	3	11 000	10 500	11 500
9	4	18 700	11 400	24 000
12	7	24 100	12 100	36 900
15	7	26 400	15 000	42 000
18	4	30 100	22 200	39 400
21	2	43 600	31 000	56 200
24	2	52 300	40 800	63 700
27	2	56 400	48 000	64 800

30	1	66 200	-	-
33	1	78 400	-	-
36	1	128 300	-	-

Advantages. Compared to broadcast spreading is the dividing of slurry over work pass more even and the ammonia emission is lower. Cheaper, bigger work width and less sensible for stones compared to injection or incorporation spreaders. Possible to spread on fields with stony or heavy soil.

Disadvantages. Compared to injection or incorporation spreaders the ammonia emissions are higher and odour is stronger, especially if the incorporation is delayed. The trailing hose spreading requires additional operation for slurry incorporation.

3.2.5 Trailing Nozzle Spreaders

Trailing nozzles spreaders are similar to trailing hose spreaders. The main difference is that the hoses are fixed on steel bars, avoiding upward movement of the hoses and securing equal distance between hoses (Figure 3.24). The hoses can also be fixed on fibre glass rods enabling lateral movement. On the lower end of the hoses are nozzles, directing slurry onto the field surface below plant leaves, diminishing number of plant parts contaminated with slurry. However, contaminated plants may be on the wheel tracks, as the plants are pressed on the ground and hoses are running over the plants. The ammonia emissions are up to 18%. Width of spreaders is between 6–36 m and prices between 28 000–86 900 € (Table 3.8). Due to big width of device, it is hard use it on small, irregular plots with steep slopes. The nozzle is made from steel (Figure 3.24a) or rubber.

Table 3.8. Working widths and prices of trailing nozzle spreaders

Working width, m	No of devices in catalogue	Price, €		
		average	min	max
6	3	29 800	28 000	32 500
9	3	32 100	19 300	41 600
12	4	41 900	20 700	57 000
15	3	44 800	24 300	60 100
18	2	48 600	30 500	66 600
21	1	74 300	-	-
24	1	86 900	-	-

Trailing shoe spreader is similar to trailing nozzle spreader, but with a shoe before the nozzle (Figure 3.24b). The shoe cuts a slot in the soil up to 2 cm deep, where slurry is directed through the nozzle. If trailing shoe is used, then plants on wheel tracks are not contaminated. The device is suitable to fertilise arable lands and grassland, as well to fertilise cereals and rapeseed during the growing time.

Figure 3.24. Trailing hose spreader is equipped with nozzles and shoes to ensure ground near and narrow slurry banding. (Photo: R. Vettik)

Advantages. Compared to broadcast spreading is the dividing of slurry over work pass more even and the ammonia emission is lower. Cheaper, bigger work width and less sensible for stones compared to injection or incorporation spreaders. Possible to spread on fields with stony or heavy soil.

Disadvantages. Compared to injection or incorporation spreaders the ammonia emissions are higher and odour is stronger, especially if the incorporation is delayed. The trailing hose spreading requires additional operation for slurry incorporation.

3.2.6 Incorporation Spreaders

Incorporation spreader consists of tank trailer with pump, distributor, hoses and disc (Figure 3.25) or tine cultivator (Figure 3.26) mounted on the rear end of trailer. The slurry is directed through the hoses to the field surface and is mixed immediately with upper 3–10 cm layer of soil by spherical discs or cultivator tines. If tools are adjusted by row width, such solutions are suitable for fertilisation of crops during vegetation time, if they are grown in wide rows (45–100 cm).

The spherical discs may have even or notched edges. If disc cultivator is used, then the slurry may be directed to ground before or behind the first disc row. The distance between discs is usually 25 cm. The stubble incorporation and slurry spreading are conveniently combined if disc cultivator is used, as both works are made within one operation including uniform mixing of soil, straw and slurry within whole tillage depth. Thereby the amounts of the spread slurry can be higher than by slot injection.

The ammonia emissions due to immediate incorporation into the soil are low – up to 5%. The slurry odour is hardly noticeable and risk for run-off on slopes is only with soil loosened by tillage. The disadvantage of incorporation spreading compared to previous slurry spreading methods is bigger requirement for drawing force and no possibility to use it during vegetation time for the crops growing in narrow rows.

The incorporation spreaders with tines have working widths 3–7.5 m and prices 8 700–15 100 € (Table 3.9).

Table 3.9. Working widths and prices of incorporation devices (with tines)

Working width, m	No of devices in catalogue	Price, €		
		average	min	max
3	1	8 700	-	-
6	1	13 000	-	-
7.5	1	15 100	-	-

Figure 3.25. Slurry incorporation spreader with stubble cultivator (Fliegl, 2016b)

The incorporation spreaders with discs have working widths 3–7.5 m and prices 19 100–51 500 € (Table 3.10).

Table 3.10. Working widths and prices of incorporation devices (with discs)

Working width, m	No of devices in catalogue	Price, €		
		average	min	max
3	2	19 800	19 100	20 400
5	4	30 800	22 900	44 200
6	4	34 100	29 400	40 100
7.5	5	39 000	30 500	51 500


Figure 3.26. Slurry incorporation spreader with disc cultivator (Photo: K. Tamm)

Advantages. Incorporation spreading combines slurry application and tillage. The ammonia emissions are lower than by trailing hose spreading thanks to immediate incorporation into the soil. The odour is very weak and the risk for slurry run-off is only with the soil loosened during the tillage. Relatively high application rates can be used if deeper tillage is used.

Disadvantages. Remarkable need for power. Broad tillage device are suitable only on fields where crops don't have to grow after spreading. For growing crops possible only if crops are growing in rows and tillage devices are adjusted according rows and the machine is steered by a GPS system.

3.2.7 Open-Slot Injectors

Open-slot injectors cut with knives or discs 20–60 mm deep slots to the soil, where the slurry is directed through rubber nozzles, the slots stay opened. The distance between slots is usually between 20–40 cm and usually the working width of the spreader is around 6 m. The intensity of the slurry flow has to be adjusted so that slurry doesn't over flood the soil surface. Suggestable spreading amount is 15–20 m^3 ha^{-1}. If discs are thicker or the shoe is following to cutting disc, then the maximum spreading amount is about 30 m^3. If the amount is bigger, then slurry exceeds slot capacity and stays on field surface.
The open-slot injectors can be classified as following:

- 1-disc devices with variable diameters, thickening towards the centre (Figure 3.27) or inclined (Figure 3.28);
- 2-disc devices, cutting V-shape slot into the soil (Figure 3.29);
- 1-disc devices with shoe forming V-shape slot (Figure 3.30).

Figure 3.27. The 1-disc open-slot injection device with the disc thickening towards the centre. (Photo: R. Vettik)

Figure 3.28. The open-slot injection device with 1 inclined disc (Photo: R. Vettik)


Figure 3.29. The 2-disc open-slot injection device (Photo: R. Vettik)

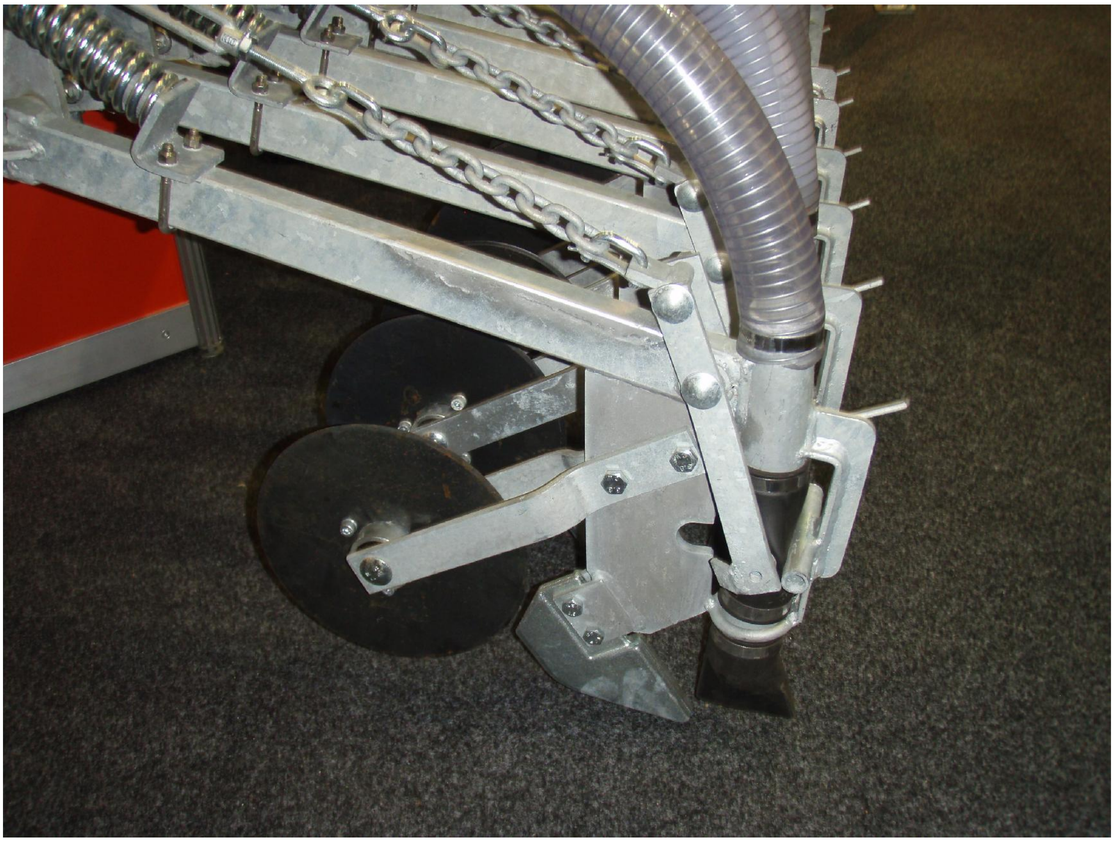
Figure 3.30. The 1-disc open-slot injection device with the shoe (Photo: R. Vettik)

Injectors are suitable to fertilise arable land and grassland as well fertilise cereals and rapeseed during growing time. Plants are not contaminated with slurry if dosage is adjusted carefully. The ammonia emissions are on average around 10%. The fields with slopes have risk of run-off if the slots are slope-directional. Injectors are not suitable for stony fields nor heavy soils, where the cutting of slot is problematical or even impossible. Open-slot injectors working widths are in range 3–6 m and prices between 14 500–76 400 € (Table 3.11).

Table 3.11. Working widths and prices of open-slot injectors

Working width, m	No of devices in catalogue	Price, €		
		average	min	max
3	2	15 000	14 500	15 500
4	2	21 300	18 000	24 500
5	5	29 500	21 200	38 000
6	11	32 300	15 500	54 800
7	7	40 500	33 200	68 100
8	5	58 700	35 900	76 400

Advantages. The open-slot injection is used to fertilise growing crops with slurry on grasslands and arable lands. Thanks to directing the slurry into soil slots, contamination of plants and ammonia emission is smaller than by trailing hose spreading.

Disadvantages. The slot cut to the soil stays opened and the ammonia emission is higher than by incorporation spreading or closed-slot injection. The suggestible spreading rate is 15-20 m^3 ha^{-1} of slurry. By using higher there is a risk that the slurry overflows on the slots and stays on the soil. There is a run-off risk on sloped fields if slits have the same direction as the slope. The injectors are not suitable for use on very stony fields or heavy soils, where the cutting of slots is problematical or impossible.

3.2.8 High-Pressure Injectors

High-pressure injector (Figure 3.31) injects the slurry into 5 cm depth with up to 13 atm. The injection devices are chambers withstanding high pressure. The devices are sliding on field surface during the working time and are lifted up for transportation. The chambers have openings on the lower side, which are used to inject slurry, coming from high pressure pump, to the soil. Above openings are rotating knives producing pulsing flow and keeping the opening clean. This injection method can be used on fields with short plants and without surface stones.

Advantages is that it can be used in the case of hidden stones.

Disadvantage is that on grassland, the plants are contaminated and slurry stays partially on the field surface, causing some ammonia emissions. It is not suggestible to use it on growing arable crops because most of the plants are injured after spreading.

Figure 3.31. High-pressure injector, injection device on right side is in working position, other 3 devices are in transportation position (Photo: R. Vettik)

3.2.9 Close-Slot Injectors

Close-slot injectors can be divided by work depth: shallow (5–10 cm) and deep (15–20 cm). In the case of shallow injection, the slurry is injected through rubber nozzles into the slots cut by discs and then the slots are closed with pressure wheels or rolls (Figure 3.32). If deep injection is used, then slurry is directed into the soil immediately behind tines (Figure 3.33). The space between injection devices is 25–50 cm. The loosened soil is falling into the slots by gravity. Ammonia emission rate is just 1%. The odour of slurry is not noticeable on injection time and the danger for run-off on fields with slopes is small.

In the case of deep close-slot injection the soil is loosened in some extent. The deep injection is used on bare arable land or on fields with wide-row crops, because the danger to injure roots of growing plants is significant. The disadvantage of such close-slot injectors is small working width and big power demand. The danger for nutrients leaching is bigger if the slurry is injected deeper. It is problematical to us this technology on the stony and heavy soils. Likewise, to the open-slot injectors, is also important to consider slurry amount by close-slot injectors to avoid slurry on the field surface. The work-width of close-slot injectors is in range 3–8 m and prices between 11 000–35 200 € (Table 3.12).

Table 3.12. Working widths and prices of close-slot injectors

Working width, m	No of devices in catalogue	Price, €		
		average	min	max
3	3	16 500	11 000	22 000
4	3	23 200	14 600	33 000
6	2	25 900	21 900	30 000
7,5	1	35 200	-	-

Figure 3.32. The shallow slots are closed by pressure wheels (Pichon, 2016)

Figure 3.33. The tines of the deep closed-slot injector (Photo: R. Vettik)

Advantages. The closed slot injectors have the lowest ammonia emissions. During the spreading the odour is very small and the risk for manure run-off is very low.

Disadvantages. The spreading width is small and power need is relatively big. If the slurry is directed deep, then the danger for leaching is higher compared to shallow injection, especially if the slurry is given in autumn when vegetation is on low level. The usage is limited mainly by soil properties – unsuitable for heavy and stony soils. As for open-slot injectors should also for closed slot, the spreading capacity should be considered avoiding slurry on the field surface.

3.2.10 Strip Injectors

Strip injection (Figure 3.34 and 3.35) is used in strip-till technology. It works by only preparing the soil where the crop is supposed to grow. Depending on the intended width of the row, up to 70% of the soil surface is not worked. This not only protects the soil against erosion and drying but also reduces the tillage costs. Simultaneously to tillage, the slurry is injected into strips. Later strips are seeded with a crop and the spaces between strips stay covered with plant residues from previous crop. The ammonia emissions are low – about 1%. The slurry odour is not noticeable and risk for run-off on slopes is only with soil loosened by tillage.
The advantages and disadvantages are same as by for closed-slot injectors.

Figure 3.34. Vogelsang Xtill S for strip-till and slurry injection (Vogelsang, 2016)

Figure 3.35. Slurry injection by strip-till. (Kverneland, 2016).

<u>The summary about slurry spreaders.</u>

There are several choices available. Which one to use, depends on local conditions. Next some outlines about choosing suitable one.

<u>Field covered with plant residues or catch crops.</u>

There is suggestion to give 20–30 kg ha^{-1} N on first tillage after harvest (Väetamise ABC) because plant residue decomposition microbiota is requires also nutrients. More plant residue means higher nutrient demand, especially highly volatile N. In manure should be considered only available ammonium nitrogen. If cattle manure has 1,3 kg ammonium N m3 and spreading with mixing device results 5% volatilization, then to achieve 20 kg ammonium N rate must be spread 16.2 t liquid manure (30/1.3/(1-0.05)=16.2 m^3 ha^{-1}. To achieve 30 kg N, 24.3 m^3 ha^{-1} must spread. Therefore optimum is between 15–25 m^3 ha^{-1}. Disc harrow results well mixed and even result through tillage depth, if set up correctly. Since manure is also mixed with soil and plant residues, there is also almost none smell issues. Shallow tillage also means that nutrients are not buried too deep to be available to plants. Nutrients are available within few weeks and will decompose over period of time. This must be take into account in next yield nutrient balance calculations.

Another possibility is use hose spreader to lay liquid manure bands to ground. In case of unacidified manure there is possibility to significant ammonia volatilization losses. Therefore it is useful to incorporate manure into soil with tillage as soon as possible.

Spring spreading before sowing.

Closed slot injector device with tines is suitable to spring time tillage on fields, where most of plant residues are decomposed and manure rate is higher. Ammonia volatilization is rather small and this is useful on high-volatilization weather conditions (high temperature, low air humidity, wind). If there is significant amount of plant residues on filed surface, then disc incorporator is more suitable. Sufficient tillage depth must be secured.
Another possibility is use hose spreader to lay liquid manure bands to ground. In case of unacidified manure there is possibility to significant ammonia volatilization losses. Therefore it is useful to incorporate manure into soil with tillage as soon as possible.

Grassland or plant covered field.

If there is growing plants present, then trailing hose/shoe or open-slot disc injectors should be used. Despite trailing hose is cheaper on favourable spreading conditions (high air humidity, low temperature and low wind speed) volatilization must be always be noticed. On high volatilization conditions, as they occur often on summertime (high temperature, low air moisture, significant wind) injection is recommended. Another option is liquid manure acidification to decrease volatilization.
Suggested spreading sate on open-slot injection is 15–20 m^3 ha^{-1}. If device has wider disc carrier or slot-dilate device, then rate may be as high, as 30 m^3 ha^{-1}. Bigger rates may not fit into slot and squirt to ground and plants. In grassland recommendation is spread liquid manure no later, than 6 weeks before cut.

Transport to field.

Liquid manure spreading machinery is expensive and should be used for spreading, not for highway travel. Special transport trailers are more economical mean to haul liquid manure from storage to field, mainly due higher speed and lower price. Calculations result 0.5–0.6 € m^{-3} lower transport costs compared to direct haulage with spreader itself. If landscape is favourable (no significant obstacles, settlements on roads) pipe transport may be considered.

Buffer tanks in fields allow minimize waiting times. Since loading area is under high stress, because it will be overridden a number of times, spreader hose feeding should be considered. Be aware of obstacles in field and sharp-edge stones on soil. Both can damage hose. Nevertheless this reduces soil thickening remarkably.

Manure spreading rate.

Despite higher rates are cheaper unit costs, environmental restrictions must be obeyed. Cost reduction is mainly because lower area requirement for given manure amount, therefore travel distance is also smaller. Less trips means also less wasted time for turning. Another limiting factor is agronomic reasonability, because proper nutrient balance must be achieved with minimum costs. If injection or incorporation is used, there should be no manure in field surface.

Same applies to solid and deep litter manure. Since nutrient content is higher, than on liquid manure, hectare rates are smaller. Example lamb manure consists 1.5 kg t^{-1} P and therefore within 5 year window only 16.5 t ha^{-1} can be used yearly.

Subcontracting manure spreading service.

Manure spreading machinery payback time is shorter on higher yearly volumes. On 100 cows dairy farm both trailing hose and open-slot devices payback time is ca. 50 years. In case of 900 cows payback time is 3 years. Therefore before making investments, calculations should be made to find unit costs for own machinery. This should be compared to service prices. In small farms outsourcing spreading service is economical choice. But be careful with availability!
Calculations were made in 100, 300 and 900 cows dairy farms. Lowest choices were accordingly: full service, own machinery, own machinery, but transport with trucks.

3.3 Spreaders for semi-liquid manure

If the semi-liquid manure is so fluid that is possible to pump, then the liquid manure technology is used. However, it should be considered that the less fluid is the liquid, the more energy is required for pumping. Thus the direct hauling technology is suggested to use for semi-liquid handling, because then there is no need for extra pumping form transporter tank to the spreader tank. The width of spreader with hoses depends on the dry matter content of semi-liquid slurry. The wider is the device, the longer are lateral hoses and the harder it is to pump the semi-liquid slurry through the hoses. The slurry with dry matter content up to 9% can be used in liquid slurry spreaders with hoses, slurry with dry matter content up to 12% can be spread with broadcast spreaders.
If solid manure distributors are used to spread semi-liquid manure to the fields then it is also recommended to use the direct hauling technology, because this kind of manure cannot to be piled on the field and loading from the transport trailer to the spreader would be difficult. The solid manure distributor can be used for the manure which has dry matter content ate least 15%.
For distribution of any kind of semi-liquid manure, any the spreader with thes feed auger on the bottom of the bin and a rotor device on aside for side spreading can be used (Figures 3.36 and 3.37).

Figure 3.36. The rotor spreader with the aside distributor and bin is suitable to distribute semi liquid manure. The outer part of the spreading device is located in front of the wheel. (Richard Western, 2012)

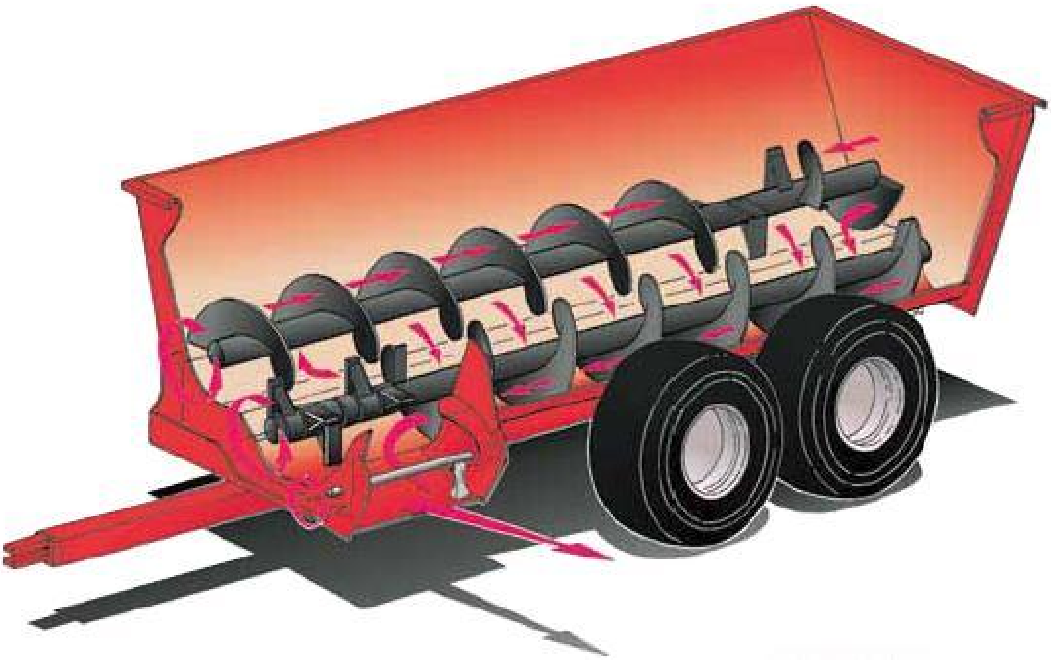

Figure 3.37. The feeding system with two augers.

In front part of the bin, on left from the wheels a hammer-type spreading device is shown, which has only one hammer visible on the picture (actually there are 12–18 of them). On the spreading the hammer snatches a batch and throws it 20 m away into the field. (Kuhn, 2009).

The semi-liquid manure can be distributed with a rear spreading solid manure distributor which has the box, guillotine door and spreading discs (Figure 3.38). In that case the box and guillotine door have to be watertight to avoid manure loss on transportation time. The spreader payload has to be kept in mind during the loading of the spreader, as the solid manure distributors may be constructed for manure with higher dry matter content and is thus lighter than semi-liquid manure. And slopes on the way of the spreader should be considered to avoid the spilling of the manure over the sides of the.


Figure 3.38. The box spreader with spreading discs.

The lower part of guillotine door with rubber sealing can be seen above upper beater. The machine builder reports that the spreader is suitable for liquid and solid manure application both. (Jeantil, 2016)

3.4 The economy of slurry spreading technologies

The economy of usage of the manure spreading Technologies is analysed depending on farm size, animal type and spreading technology. Calculated is in which sample farms is profitable to use own spreader and in which farms is more economic to order spreading from service provider.

3.4.1 The calculation model

A calculation model has used to determine optimum volume of slurry tanker according farm conditions for every farm type and size. The optimality criterion is minimum slurry distribution cost in condition that the limits of the model are satisfied.

The model to determine optimum slurry tanker volume for a farm is consisting of several steps:
1) selecting a set of slurry tankers with different tank volumes and defining pump capacity, spreader width and required tractor power for every volume;
2) calculating the spreading performance for every slurry tanker depending on average distance between slurry storage and fields and average application rate;
3) calculating the cost of work depending on the farms parameters (annual slurry production, average distance between slurry storage and fields, average application rate) if slurry is transported with tanker itself;
4) calculating the cost of slurry handling for every spreader if slurry is transported with separate tank vehicle(s); and
5) defining required number of tankers in farm; and
6) selecting the cheapest solution.

The cheapest solution is selected from all calculations made for both cases - if slurry is transported from storage to fields with 1) tanker itself and 2) separate tank vehicle(s).

The limits used in the present method are following:
1) first, the distributor is selected and afterwards the tractor is selected by distribution equipment; thus, the power requirement is not limited;
2) the tractor has enough power to apply maximum speed for transportation;
3) work method is the method of interrupted passes, application continues till the tank is empty and after reloading, the pass will be continued at the same place where it stopped;
4) application rate is the average rate weighted by crop areas planned to fertilise with slurry in the farm, and
5) the loading and unloading capacities are equal,
6) the transportation capacity of separate transportation tanks is sufficient to allow distribution without stops.

If calculations show that one spreader is too small for farm, then the combination of several spreaders is searched by minimum cost and sufficient capacity. The cost of solution (€ m^{-3}) is calculated with formula:

$$K = \frac{\sum_{i=1}^{n} P_i Y_i}{Y}$$

where P_i – work cost of specific slurry spreader i, € m^{-3};
Y_i - annual slurry distributed by spreader i in the farm, m^3
Y – annual slurry production in the farm, m^3 and
n – number of slurry spreaders in solution.

The sufficiency of capacity is controlled with the formula

$$A_{\min} \leq \sum_{i=1}^{n} w_i \ ,$$

where A_{min} – minimum slurry distribution capacity to serve maximum annual number of days for slurry distribution, m^3 h^{-1} and

w_i - spreading capacity of a slurry distributor *i* in found solution, m^3 h^{-1}.

The minimum capacity required to distribute the annual amount of slurry in the farm is by the ASAE Standard (2003) calculated by estimating the number of days yearly within which the operation should be accomplished, and by determining the probability of a annual working days in this time span:

$$A_{\min} = \frac{Y}{DT\tau}$$

where

A_{min} is the minimum capacity required to distribute the amount of slurry in the farm, m^3 h^1;
D – number of days which are available for slurry distribution, days;
T - expected time available for work each day, h day^{-1} and
τ - the probability of a working day during timespan, decimal, 0.8.

Distributor performance *w* is calculated with formula

$$w = \frac{60Q}{t_c}$$

where *Q* – tank volume, m^3 and
t_c - cycle time, needed to bring the tank-full of slurry from storage to the soil, min.

The cycle time for handling one tank-full is found with formula (Bogun & Jõgeva, 2005):

$$t_c = t_d + t_w + t_t + t_m + t_r\ ,$$

where

t_d - travel time from the reloading point to the work pass and back, min;
t_w - distribution time on the pass, min;
t_t - time for turns in the end of passes, min;
t_m - time for handling and turning before and after the loading, min and
t_r - loading time, min.

Most of values of these elements are been calculated with formulas given in Table 3.13.

Table 3.13. Formulas to compute the elements of cycle t_c (Bogun & Jõgeva, 2005)

Parameter	Calculation formula	Definitions
Transportation time	$t_d = 120\left(\frac{d_{road}}{v_{road}} + \frac{d_p}{v_p}\right)$	*b* - effective working width of tanker, m; b_n - nominal width of spreader, m; d_p - distance from field access to the pass, km;
Spreading time on the pass	$t_w = \frac{600Q}{bhv_w}$	d_{road} - distance between storage and field, km; *h* - slurry application rate, m^3 ha^{-1};
Effective width	$b = 0.01 b_n \varphi$	*l* - length of pass, km; t_{1t} - average time for one turn, h.
Work speed	$v_w = \frac{10W_u}{bh}$	v_p - average idle speed on the plot, km h^{-1};
Time for turns in the end of passes	$t_t = \frac{3.14Q}{100hl\,v_t}$	v_{road} - average road speed, km h^{-1} v_t - average turning speed in end of passes, km h^{-1} v_w - average work speed, km h^{-1}
Reloading time	$t_r = 60\frac{Q}{W}$	*W* - loading capacity, m^3 h^{-1}; W_u - unloading capacity, m^3 h^{-1}; *φ* - factor of use of nominal width, %.

The performance of a slurry tanker is affected by different variables, such as work width and speed, transport distance, by time for prepare and finish loading, loading capacity and tank volume.

The average speed is 25 km h^{-1} on the road and 6 km h^{-1} for idle travel on the plot. The time for handling and turning before and after the loading is 1.93 min (Sørensen 2003). The factor of use of nominal width of distributor φ is 100%. The life time of spreader is 10 years.

In all experiments, the length of working day is 10 h and the probability of workday is 0.8 (it means that probably 80% of planned work time actually may be used).

The work costs for tractor and spreader are calculated separately, because for tractor cost are calculated diesel, labour, and traffic costs, which are not calculated for distributor. First the tractor hourly cost is calculated, then spreader work cost per m^3 of slurry and then tractor cost per m^3 by spreading capacity of spreader. Finally tractor and spreader costs are added.

The formulae for calculating the components of hourly cost of the machines have been much used in different research concerning the economic usage of agricultural machines.

The sum of the other components of the hourly cost of a tractor belonging to the spreading unit is calculated with the following formula:

$$P_t = c_a + c_i + c_k + c_g + c_f + c_m + c_j + c_h ,$$

where c_a - depreciation costs of machine, € h^{-1};
c_i - interest, € h^{-1};
c_k - insurance of machine, € h^{-1};
c_g - costs of housing machine, € h^{-1};
c_f - fuel cost of tractor, € h^{-1};
c_m - lubrication cost of machine, € h^{-1};
c_j - labour cost, h^{-1} and
c_h - maintenance cost of machine, € h^{-1}.

A linear method generally is used to calculate the depreciation allowance of machines

$$c_a = \frac{H - H_r}{T_a W} ,$$

where H - purchase price of machine, €;
H_r - remaining value of machine, €;
T_a - lifespan of machine, years and
W - annual work capacity, h year^{-1}.

Interest is calculated as an average from the life-span of a machine:

$$c_i = \frac{a_p i_p H \left(1 - \frac{O_f}{100}\right)}{2 \cdot 100 T_a W} ,$$

where a_p - length of loan period, years;
i_p - rate of interest, % year^{-1} and
O_f - rate of self-financing, % from loan sum.

The 2 in formula (3.11) is used to calculate the average remaining value of the machine.

Housing costs of a machine

$$c_g = \frac{H_b A_b}{W}\left[\frac{1}{T_b} + \left(\frac{i_p + i_{bk}}{200}\right)\right],$$

where H_h - cost for housing unit, € m^{-2};
A_h - housing area needed for the machine, m^2;
T_h - lifespan of housing room, years and
i_{hk} - insurance rate of housing room, % from price.

Tractor insurance

$$c_k = \frac{\frac{i_{vk}H}{200} + I_k}{W},$$

where i_{vk} - rate of property insurance, % year^{-1} and
I_k - traffic insurance and technical inspection charge, EUR year^{-1}.

Fuel costs

Fuel consumption is calculated with the following formula:

$$G = \frac{q\xi N_m}{\rho},$$

and fuel cost with the following formula:

$$c_f = r_k G,$$

where q - specific fuel consumption, kg (kWh)$^{-1}$;
ξ - factor considering daily average diesel consumption depending on work type: hard work 0.6-0.7, medium work 0.4-0.5 and easy work 0.3;
N_m - nominal effective power of the engine of a tractor or a self-propelled machine, kW;
ρ - density of fuel, kg l^{-1}; for diesel fuel ρ= 0.86 kg l^{-1} and
r_k - price of fuel, € l^{-1}.

Lubricant cost

$$c_m = 1{,}2\frac{ur_m G}{100},$$

where u - rate of lubricant consumption, % of fuel consumption; and
r_m - price of lubricant, € l^{-1}.

The r_m is the price of engine oil. The cost k_m also includes the cost of other lubricants such as transmission oil and others. The other lubricants are estimated to be somewhat more expensive than engine oil and therefore the coefficient 1.2 is used.

Maintenance cost

Costs for periodical technical maintenance and repair are taken into account as maintenance costs:

$$c_b = \frac{sM_a}{100W},$$

where s - costs for maintenance, % of replacement price of machine and
M_a - replacement price of machine (for new machine at the same as purchase price), €.

Labour cost

$$c_j = p\left(1+\frac{p_h}{100}\right)\left(1+\frac{m_s+m_h+m_t+m_p}{100}\right),$$

where p - operator's hourly fee, € h^{-1};

p_h - rate of additional compensation for maintenance, % of operator's hourly fee;

m_s - social tax rate, %;

m_h - health insurance rate, %;

m_t - unemployment insurance rate, % and

m_p - vacation fee rate, %.

In addition to spreading costs, also slurry-mixing costs are calculated. An electrical mixer is used and mixing time is equal to spreading time.

If a broadcast spreader is used for the slurry distribution then the disc cultivation cost is also calculated to achieve comparable conditions to incorporation spreading.

In the calculation where separate tanker is used to transport slurry from storage to the field is considered that the tankers are rental machines from service providers. The cost of slurry transportation is 1.4 € m^3 (includes the cost of diesel for up to 7 km). Starting from 7 km is added 0.1 € per km to m^3-price. Mixing and pumping is ca 0.5 € m^{-3}. Open-slot injection-1.6 € m^{-3}. Incorporation spreading - 1.8 € m^{-3}.

3.4.2 Farms and machinery

For comparison three different size model enterprises were selected (Table 3.14) for dairy, pork, beef and lamb production.

Table 3.14. Size classes of theoretical farms

Milk production farms	Pig farms	Beef cattle farms	Sheep farms
Dairy cows	Fattening places	Nurse cows	Sheep
100	2 000	30	50
300	5 000	50	100
900	10 000	100	300

The spreading unit for spreading liquid manure has composed from tank trailer with suitable spreading apparatus and tractor with necessary engine power. Spreading apparatus was either trailing hose, open-slot injection or disc incorporator. Technical parameters and average prices (Table 3.15) are from Price Comparative Catalogue at January 2016 (Estonia). Prices in Latvia are presented on Table 3.16.

Table 3.15. Parameters and average prices (without VAT) of liquid manure applicators in Estonia

Liquid manure tank	Tractor	Trailing hose device	Open slot injector	Disc incorporator

Volume, m^3	Pump, l min^{-1}	Price, €	Power, kW	Price, €	Width, m	Price, €	Width, m	Price, €	Width, m	Price, €
5	2 500	12 850	75	53 000	9	18 740	3	15 000	3	19 750
10	4 000	32 790	102	72 000	12	24 130	4	21 250	4	26 330
15	5 000	54 420	145	103 000	15	26 350	4.5	25 350	4.5	27 670
20	6 000	96 800	175	120 000	18	30 050	5	29 450	5	30 750
25	8 000	145 500	205	170 000	24	52 250	6	32 300	6	34 130

Table 3.16. Parameters and average prices (without VAT) of liquid manure applicators in Latvia

Liquid manure tank			Tractor		Trailing hose device		Open slot injector		Disc incorporator	
Volume, m^3	Pump, l min^{-1}	Price, €	Power, kW	Price, €	Width, m	Price, €	Width, m	Price, €	Width, m	Price, €
5	2 500	7 000	88	44 800	9	10 000	-	-	-	-
10	4 000	22 000	101	48 400	12	12 000	4	20 000	4	21 000
16	5 000	34 300	150	84 700	15	16 700	4.5	20 700	4.5	21 700
20	6 000	55 300	150	84 700	-	-	5	21 700	5	22 700
20	6 000	55 300	180	102 800	18	17 200	6	24 700	6	25 700

Spreading units for spreading solid manure composed from spreading box trailer with certain payload and tractor for necessary engine power are presented in Table 3.17. for Estonia and Table 3.18 in Latvia.

Table 3.17. Parameters and average prices (without VAT) of solid manure applicators in Estonia

Payload of the spreader, t	Tractor		Vertical-axis beaters and discs	
	Power, kW	Price, €	Width, m	Price, €
3.5	50	36 000	3 (2-4)*	15 000*
5	75	53 000	6 (6-10)	18 000
8	102	72 000	7 (6-10)	21 500
10	145	103 000	8 (8–12)	32 700
15	175	120 000	10 (8–12)	34 100
20	205	170 000	12 (12-20)	53 800

*- spreader with horizontal-axis beaters

Table 3.18. Parameters and average prices (without VAT) of solid manure spreaders in Latvia

Load capacity of the	Tractor	Vertical-axis beaters and discs

spreader, t	Power, kW	Price, €	Width, m	Price, €
5	88	44 800	6 (6-10)	9 500
8	101	48 400	7 (6-10)	15 700

The numbers in tables 3.17 and 3.18 show that the machinery prices are in Latvia lower than in Estonia.

To find optimal solution for theoretical enterprises, calculations were made, according to average hauling distance, spreading day count, manure yearly amount and required spreading rate. If one tank or box trailer is not enough, then another smaller unit has added. Costs of both units have summed. Results are expressed as € t^{-1}.

The labour costs without taxes used in calculations was 5 € h^{-1} for Estonia and Latvia both. The cost of fuel is 0.65 € l^{-1} in Latvia and 0.7 € l^{-1} in Estonia.

Yearly manure amounts in Latvia for all year indoor herding are calculated according to National standard for manure production and management (http://www.lad.gov.lv/files/l121nacionalais_standarts_kutsmeslu_ieguve_un_apsaimniekosana.pdf) (table 3.19).

Table 3.19. Yearly manure production in Latvia.
(National standard for manure production and management, http://www.lad.gov.lv/files/l121nacionalais_standarts_kutsmeslu_ieguve_un_apsaimniekosana.pdf)

Animal group	Solid manure, t	Liquid manure,t
Dairy cow (milk production 6 000 kg yearly)	15.5	30
Calf, <6 month	2.6	
Heifer, >6 month	8	15
Young bulls, >6 month	11.1	20.5
Pigs	1	2
	Deep litter manure	
Beef cattle (> 24 month) with calf	12	
Calf, <6 month	2.6	
Heifer, >6 month	11.1	
Grown bulls	14	
Sheep	1.3	

Dairy farms

Yearly manure amounts for all year indoor herding are calculated according to ordinance nr. 71 of Ministry of Agricultural Affairs (Põllumajandusministri määrus nr 71, lisa 3, 2014).

Calculations made separately for two different herding systems:

A – animals over six months old producing liquid manure and calves producing solid manure (most liquid strategy);

B – only milking cows are producing liquid manure and all youngsters producing solid manure (liquid/solid strategy).

Calculation results are been presented in Table 3.20 for Estonia and Table 3.21 for Latvia.

Table 3.20. Herd sizes and produced manure amounts of theoretical farms in Estonia

Dairy cows	Young animals	Produced liquid manure and solid manure (calves) amount, t y^{-1} (A)		Produced liquid manure and solid manure (young animals) amount, t y^{-1} (B)	
		Liquid manure	Solid manure	Liquid manure	Solid manure
100	92	3 226	67	2 470	857
300	276	9 678	201	7 410	2 570
900	828	29 032	603	22 230	7 710

Table 3.21. Herd sizes and produced manure amounts of theoretical farms in Latvia

Dairy cows	Young animals	Produced liquid manure and solid manure (calves) amount, t y^{-1} (A)		Produced liquid manure and solid manure (young animals) amount, t y^{-1} (B)	
		Liquid manure	Solid manure	Liquid manure	Solid manure
100	100	4 110	68	3 000	660
300	300	12 330	203	9 000	1 979
900	900	36 990	608	27 000	5 936

Grassland acreage calculations are based on assumptions that forage originates from farm fields and all produced manure must be used (30 t ha^{-1} for liquid and 25 t ha^{-1} for solid manure) on the farm fields. Hauling distances calculated in accordance with required acreage are been presented in Table 3.22 for Estonia and 3.23 for Latvia.

Calculations for **Estonia** assume manure P-content on DM 10%. According to The Agricultural Research Centre average results this was 0.82 kg t^{-1} and since crop rotation average can P be given 25 kg ha^{-1}, spreading rate can be up to 30 t ha^{-1}.

If manure P-content is smaller, than previously given, higher rates can be used. Example: if 5.5% DM content cattle manure consists average 0.5 kg t^{-1} phosphorus, it can be spread on rate 50 t ha^{-1}. If N-content is 2.7 kg t^{-1} and maximum nitrogen amount is 170 kg N ha^{-1}, then by nitrogen rate can be as high as 63 t ha^{-1}. But this rate cannot be spread with open-slot device, since slot will be overflowing and manure left on field surface both spoils plants and loses nitrogen.

Phosphorus usage is not limited in **Latvia**. Average spreading rate is 40 t ha^{-1}. This rate was also base for calculations.

Table 3.22. Land requirements in theoretical farms in Estonia (s*preading rate liquid manure 30 t ha^{-1} and solid manure 25 t ha^{-1}*)

Required land for manure spreading, ha	The

A			B			average transport distance, km
Liquid manure	Solid manure	Total area	Liquid manure	Solid manure	Total area	
108	3	111	82	34	116	2
323	8	331	247	103	350	4
968	24	992	741	308	949	7

Table 3.23. Land requirements in theoretical farms in Latvia (*spreading rate liquid manure 40 t ha^{-1} and solid manure 35 t ha^{-1}*)

Required land for manure spreading, ha				The average transport distance, km
A		B		
Liquid manure	Solid manure	Liquid manure	Solid manure	
103	2	75	19	2
308	6	225	57	4
925	17	675	170	6

A. The strategy if most manure is liquid

According to ECAC inquiry average spreading time with own work was 62 days for cattle farms. For every farm, cheapest variant was picked from 5 machine choices (Table 3.15 for Estonia and 3.16 for Latvia). Results for hose spreader are presented on Table 3.24 and Open-Slot Injection on Table 3.27 for Estonia and Tables 3.26 and 3.28 for Latvia accordingly.

Table 3.24 Spreading with **trailing hose** devices for Estonia. *Spreading rate 30 t ha^{-1}*. The number in the beginning of spreading equipment is showing number of required spreaders.

Liquid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**				
3 226	2	62	1 x 10 m^3	5.20
9 678	4	62	1 x 15 m^3	3.71
29 032	7	62	2 x 20 m^3	4.03
Transportation with separate **tanker**				
3 226	2	62	1 x 5 m^3	4.66
9 678	4	62	1 x 10 m^3	3.08
29 032	7	62	1 x 10 m^3	2.62

The calculations are made to clarify also the spreading rate effect on spreading costs for rate 50 t ha^{-1}. Higher rate results in less area, reducing also filed acreage and average hauling distance (Table 3.25).

Table 3.25. Spreading with **trailing hose** devices for Estonia. *Spreading rate 50 t ha^{-1}*

Liquid manure, t	Required land for slurry spreading, ha	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**					
3 226	65	2	62	1 x 10 m^3	5.19
9 678	194	3	62	1 x 15 m^3	3.28
29 032	581	5	62	1 x 20 m^3 and 1 x 10 m^3	3.30
Transportation with separate **tanker**					
3 226	65	2	62	1 x 5 m^3	4.65
9 678	194	3	62	1 x 10 m^3	3.06
29 032	581	5	62	1 x 10 m^3	2.50

Table 3.26. Spreading with **trailing hose** devices for Latvia. *Spreading rate 40 t ha^{-1}*

Liquid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**				
4 110	2	62	1 x 10 m^3	3.60
12 330	4	62	1 x 16 m^3	2.76
36 990	6	62	2 x 20 m^3 and 1 x 5 m^3	3.05
Transportation with separate **tanker**				
4 110	2	62	1 x 10 m^3	3.52
12 330	4	62	1 x 10 m^3	2.53
36 990	6	62	1 x 10 m^3	2.20

Table 3.27. Spreading with **open slot injectors** for Estonia. *Spreading rate 30 t ha^{-1}*

Liquid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**				
3 226	2	62	1 x 10 m^3	5.58

9 678	4	62	1 x 15 m^3	4.02
29 032	7	62	2 x 20 m	4.34
Transportation with separate **tanker**				
3 226	2	62	1 x 5 m^3	4.96
9 678	4	62	1 x 10 m^3	3.32
29 032	7	62	1 x 10 m^3	2.82

Table 3.28. Spreading with **open slot injectors** for Latvia. *Spreading rate 40 t ha^{-1}*

Liquid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**				
4 110	2	62	1 x 10 m^3	3.90
12 330	4	62	1 x 16 m^3	2.92
36 990	6	62	2 x 20 m^3 and 1 x 10 m^3	3.03
Transportation with separate **tanker**				
4 110	2	62	1 x 10 m^3	3.82
12 330	4	62	1 x 10 m^3	2.70
36 990	6	62	1 x 10 m^3	2.33

Contracted full service (mixing, pumping, hauling with transport tankers and spreading on field) spreading costs up to distance 6 km are 3.5 € t^{-1}. Hauling distance 7 km adds 0.1 € t^{-1}. Therefore full service costing less on manure amount 3 226 t. On 9 678 t and 29 032 t amounts contracted hauling and own spreading is most economical options.

Open-slot spreading in **Latvia** will cost 3.5 € m^3.

If solid manure is not spread from last seeding date to first harvesting date (eg. from May 10 to August 10), then there are available 163 possible days (including weekends) from whole season to use for manure spreading. Consider 5 working days and 2 holidays for week, results in 116 spreading days. For every farm from six possible machines choices (from table 3.17 for Estonia and 3.18 for Latvia) least expensive was chosen. In the table 3.29 are most economical results for every farm for Estonia and 3.30 for Latvia.

Table 3.29. Solid manure spreading (**direct haulage**) for Estonia. *Spreading rate 25 t ha^{-1}*

Solid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
67	0.5	116	1 x 3.5 t	15.33
201	1	116	1 x 3.5 t	7.55
603	2	116	1 x 8 t	5.32

Table 3.30 Solid manure spreading (**direct haulage**) for Latvia. *Spreading rate 35 t ha^{-1}*

Solid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
68	0.5	116	1 x 5 t	9.09
203	1	116	1 x 5 t	5.18
608	2	116	1 x 8 t	4.32

B. Liquid/solid strategy.

For every farm, the cheapest variant was picked from 5 machine choices (Table 3.15 for Estonia and Table 3.16 for Latvia). Results for hose spreader are presented on Table 3.31 and Open-Slot Injection on Table 3.34 for Estonia and Tables 3.33 and 3.35 for Latvia accordingly.

Table 3.31 Spreading with **trailing hose** devices for Estonia. *Spreading rate 30 t ha^{-1}*. The number in the beginning of spreading equipment is showing number of required spreaders

Liquid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**				
2 470	2	62	1 x 10 m^3	6.30
7 410	4	62	1 x 15 m^3	4.19
22 230	7	62	1 x 20 m^3 and 1 x 10 m^3	4.28
Transportation with **separate tanker**				
2 470	2	62	1 x 5 m^3	5.33
7 410	4	62	1 x 10 m^3	3.34
22 230	7	62	1 x 10 m^3	2.71

The calculations are been made to clarify also the spreading rate effect on spreading costs for rate 50 t ha^{-1}. Higher rate results less area, reducing also field acreage and average hauling distance (Table 3.32).

Table 3.32 Spreading with **trailing hose** devices for Estonia. *Spreading rate 50 m^3 ha^{-1}*

Liquid manure, t	Required land for slurry spreading, ha	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**					
2 470	49	2	62	1 x 10 m^3	6.28
7 410	148	3	62	1 x 15 m^3	3.72

22 230	445	5	62	1 x 25 m^3	3.42
Transportation with separate **tanker**					
2 470	49	2	62	1 x 5 m^3	5.31
7 410	148	3	62	1 x 10 m^3	3.32
22 230	445	5	62	1 x 10 m^3	2.59

Table 3.33 Spreading with **trailing hose** devices for Latvia. *Spreading rate 40 t ha^{-1}*

Liquid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**				
3 000	2	62	1 x 10 m^3	4.45
9 000	4	62	1 x 16 m^3	3.10
27 000	6	62	1 x 20 m^3 and 1 x 10 m^3	3.09
Transportation with separate **tanker**				
3 000	2	62	1 x 10 m^3	4.07
9 000	4	62	1 x 10 m^3	2.71
27 000	6	62	1 x 10 m^3	2.26

Table 3.34 Spreading with open **slot injectors** for Estonia. *Spreading rate 30 t ha^{-1}*

Liquid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**				
2 470	2	62	1 x 10 m^3	6.74
7 410	4	62	1 x 15 m^3	4.52
22 230	7	62	1 x 20 m^3 and 1 x 15 m^3	4.61
Transportation with separate **tanker**				
2 470	2	62	1 x 5 m^3	5.68
7 410	4	62	1 x 10 m^3	3.61
22 230	7	62	1 x 10 m^3	2.91

Contracted full service (mixing, pumping, hauling with transport tankers and spreading on field) spreading costs up to distance 6 km are 3.5 € t^{-1}. Hauling distance 7 km adds 0.1 € t^{-1}. Therefore full service costing less on manure amount 2 470 t and 7 410 t. The 22 230 t for contracted hauling and own spreading is most economical options.

Table 3.35 Spreading with open **slot injectors** for Latvia. *Spreading rate 40 t ha^{-1}*

Liquid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**				
3 000	2	62	1 x 10 m^3	4.82
9 000	4	62	1 x 16 m^3	3.28
27 000	6	62	1 x 20 m^3 and 1 x 16 m^3	3.14
Transportation with separate **tanker**				
3 000	2	62	1 x 10 m^3	4.44
9 000	4	62	1 x 10 m^3	2.91
27 000	6	62	1 x 10 m^3	2.40

Full service costing less on manure amount 3 000 t. The 27 000 t contracted hauling and own spreading are most economical options.

If solid manure will not spread from last seeding date to first harvesting date (from 10. may to 10. august), there will be 163 possible spreading days, including weekends. Consider 5 working days and 2 holidays for week, results 116 spreading days. For every farm from six possible machines choices (from table 3.17 for Estonia and 3.18 for Latvia) least expensive was chosen. On Table 3.36 are most economical results for every farm are been presented for Estonia and Table 3.37 for Latvia.

Table 3.36 Solid manure spreading (**direct haulage**) for Estonia. *Spreading rate 25 t ha^{-1}*

Solid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
857	2	116	1 x 8 t	4.87
2570	5	116	1 x 8 t	5.44
7 710	7	116	1 x 8 t	6.07

Table 3.37 Solid manure spreading (**direct haulage**) for Latvia. *Spreading rate 35 t ha^{-1}*

Solid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
660	2	116	1 x 8 t	4.26
1979	4	116	1 x 8 t	4.28
5 936	6	116	1 x 8 t	4.77

Pig production.

Liquid manure amounts are calculated according to ordinance nr. 71 of Estonian Ministry of Agricultural Affairs (Põllumajandusministri määrus nr 71, lisa 3, 2014) and presented on Table 3.38 for Estonia with necessary acreage for spreading rate 25 t ha^{-1}. Latvian results are been presented on Table 3.39 for spreading rate 40 t ha^{-1}

Calculations for **Estonia** assume manure P-content on DM 5%. According to The Agricultural Research Centre average results this was 1.0 kg t^{-1} and since crop rotation average can P be given 25 kg ha^{-1}, spreading rate can be up to 25 t ha^{-1}.

Phosphorus usage is not limited in **Latvia**. Average spreading rate is 40 t ha^{-1}. This rate was also base for calculations.

Table 3.38 Herd sizes and produced manure amounts of theoretical farms for Estonia

Fattening places	Produced liquid manure, t y^{-1}	Required land for manure spreading, ha	The average transport distance, km
2 000	3 200	128	2
5 000	8 000	320	4
10 000	16 000	640	6

Tabel 3.39 Herd sizes and produced manure amounts of theoretical farms for Latvia.

Fattening places	Produced liquid manure, t y^{-1}	Required land for manure spreading, ha	The average transport distance, km
2 000	4 000	100	2
5 000	10 000	250	3
10 000	20 000	500	5

According to ECAC inquiry average spreading time on own work was 75 days on pork farms. For every farm, cheapest variant was picked from 5 machine choices (Table 3.15 for Estonia and Table 3.16 for Latvia). Results for disc incorporator are presented on Table 3.40 for Estonia and 3.41 for Latvia.

Table 3.40 Spreading with **disc incorporator** for Estonia. *Spreading rate 25 t ha^{-1}*. The number in the beginning of spreading equipment is showing number of required spreaders.

Liquid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
		Transportation with **spreader**		
3 200	2	75	1 x 15 m^3	4.78
8 000	4	75	1 x 15 m^3	4.07
16 000	6	75	1 x 20 m^3	3.99
		Transportation with separate **tanker**		

3 200	2	75	1 x 10 m^3	4.66
8 000	4	75	1 x 10 m^3	3.56
16 000	6	75	1 x 10 m^3	3.20

Contracted full service (mixing, pumping, hauling with transport tankers and spreading on field) spreading costs up to distance 6 km are 3.7 € t^{-1}. Therefore full service costing less on manure amount 3 200 t. On 8 000 t and 16 000 t amounts contracted hauling and own spreading is most economical option.

Table 3.41 Spreading with **disc incorporator** for Latvia. *Spreading rate 40 t ha^{-1}*

Liquid manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
Transportation with **spreader**				
4 000	2	75	1 x 16 m^3	3.18
10 000	3	75	1 x 16 m^3	2.57
20 000	5	75	1 x 20 m^3	2.80
Transportation with separate **tanker**				
4 000	2	75	1 x 16 m^3	3.47
10 000	3	75	1 x 16 m^3	2.80
20 000	5	75	1 x 16 m^3	2.59

Own equipment is most economical on amounts 4 000 and 10 000 t. The 20 000 t for contracted hauling and own spreading is most economical option.

<u>Beef production</u>

Manure amounts for periodical pasturing are calculated according to amendment 4 of ordinance no. 71 of Estonian Ministry of Agricultural Affairs (Põllumajandusministri määrus nr 71, lisa 4, 2014) and presented on Table 3.42 for Estonia. Manure amounts for Latvia are calculated by data in Tabel 3.19 and results are shown in Table 3.43 for.

Calculation assumes, that phosphorus content is 1,4 kg t-1 and crop rotation average limit over 5 years 25 kg ha^{-1} will not be exceed. Spreaded amount is 25 t ha^{-1} in Estonia and since in Latvia is no limitation to P, 35 t ha^{-1} in Latvia.

Table 3.42. Herd sizes and produced manure amounts of theoretical farms for Estonia. *Spreading rate 25 t ha^{-1}*

Nurse cows	Young animals	Deep litter manure, t y^{-1}	Acreage required, ha
30	60	455	18

50	100	758	30
100	200	1 515	61

Table 3.43. Herd sizes and produced manure amounts of theoretical farms for Latvia. *Spreading rate 35 t ha^{-1}*

Nurse cows	Young animals	Deep litter manure, t y^{-1}	Acreage required, ha
30	60	599	17
50	100	998	29
100	200	1 995	57

For every farm, cheapest variant was picked from 5 machine choices (Table 3.17 for Estonia and 3.18 for Latvia). Results are been presented on Table 3.44 for Estonia and 3.45 for Latvia. For solid manure and deep litter manure, spreading day count is the same.

Table 3.44. Deep litter manure spreading (**direct haulage**) for Estonia. *Spreading rate 25 t ha^{-1}*

Deep litter manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
455	1	116	1 x 3.5 t	5.17
758	3	116	1 x 8 t	5.44
1 515	5	116	1 x 8 t	5.69

Table 3.45. Deep litter manure spreading (**direct haulage**) for Latvia. *Spreading rate 35 t ha^{-1}*

Deep litter manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
599	1	116	1 x 5 t	4.00
998	2	116	1 x 5 t	3.50
1 995	3	116	1 x 8 t	3.78

Conclusion. Solid manure handling was cheapest in smallest farm because the direct hauling method was used. Smaller farms have shorter transportation distance and thus lower manure handling cost. However, in Latvia, because of 5 cents lower fuel price, bigger manure amount per hectare, and thus smaller area for spreading and shorter distances for transportations, the manure handling is cheapest in biggest farm.

Sheep production

Manure amounts for periodical pasturing are calculated according to amendment 4 of ordinance no. 71 of Estonian Ministry of Agricultural Affairs (Põllumajandusministri määrus nr 71, lisa 4,

2014) and presented on Table 3.46 for Estonia. Manure amounts for Latvia are calculated by data in Tabel 3.19 and results are shown in Table 3.47 for.

Calculation assumes, that phosphorus content is 1.8 kg t^{-1} and crop rotation average limit over 5 years 25 kg ha^{-1} will not be exceed. Spread amount is 25 t ha^{-1} in Estonia and since in Latvia is no limitation to P, 35 t ha^{-1} in Latvia.

Table 3.46. Herd sizes and produced manure amounts of theoretical farms for Estonia. *Spreading rate 25 t ha^{-1}*

Sheep	Deep litter manure, t y^{-1}	Acreage required, ha
50	70	3
100	140	6
300	420	17

Table 3.47. Herd sizes and produced manure amounts of theoretical farms for Latvia. *Spreading rate 35 t ha^{-1}*

Sheep	Deep litter manure, t y^{-1}	Acreage required, ha
50	65	2
100	130	4
300	390	11

For every farm, cheapest variant was picked from 6 machine choices (Table 3.17 for Estonia and Table 3.18 for Latvia). Results are been presented on Table 3.48 and 3.49 for solid and deep litter manure spreading day count is the same.

Table 3.48. Deep litter manure spreading (**direct haulage**) for Estonia. *Spreading rate 25 t ha^{-1}*

Deep litter manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
70	0.5	116	1 x 3.5 t	13.03
140	1	116	1 x 3.5 t	8.50
420	2	116	1 x 3.5 t	5.89

Table 3.49. Deep litter manure spreading (**direct haulage**) for Latvia. *Spreading rate 35 t ha^{-1}*

Deep litter manure, t	The average transport distance, km	Number of spreading days	Spreading equipment	Spreading cost, € t^{-1}
65	0.5	116	1 x 5 t	9.38
130	1	116	1 x 5 t	6.36
390	2	116	1 x 5 t	4.71

Conclusion:

Solid manure handling was cheapest in biggest sheep farm because they had bigger manure amount and small differences between transportation distances had no significant impact on manure handling costs.

It can be resumed that direct hauling technology of solid manure in cases if the manure amounts are very small, like in sheep farms, then the costs per manure tonne are bigger if farm is smaller. Although the transportation distances in smaller farms are shorter.

If the solid manure amounts are big enough like in beef farms, then the costs per manure tonne are the bigger the larger is the farm. The reason is that for distributing of bigger amounts are larger areas required and then the transportation distances are so long that it rises cost of solid manure handling.

3.4.3 Economic Effect of Ammonia Emission by Slurry Spreading

The calculations were made for a sample situation where is summed slurry handling costs and cost caused by the ammonia loss by different spreading technologies.
The initial data for calculations: the average transportation distance from storage to the field is 3 km, the prehaulage is used to get slurry to the field, the annual amount of slurry produced in farm is 20 000 m^3, the spreader tank size is 15 m^3, the hectare rate for pig slurry is 25 t ha^{-1} (NH_4-N 2.6 kg t^{-1}) and for cattle slurry 30 t ha^{-1}.

The results are given in the tables 3.50, 3.51 and graphically on figures 3.39, 3.40.

Table 3.50. Pig slurry handling cost plus cost caused by the ammonia loss by different spreading technologies

Spreading technologies	Slurry handling cost, € ha^{-1}	Ammoniacal-N loss*, %	N loss, kg ha^{-1}	Cost caused by the additional N-fertilizer, € ha^{-1}	Handling + N loss, € ha^{-1}
Broadcast spreading	56	34-100	22-65	17-51	73-107
Broadcast spreading, incorporation during 12 h	56 + 18	26-79	17-51	13-40	87-114
Trailing hose spreading	70	20-80	13-52	10-41	80-111
Trailing hose spreading, incorporation during 12 h	70 + 18	8-32	5-21	4-16	92-104
Trailing hose spreading (height of plants >10 cm)	70	8-50	5-33	4-26	74-96
Trailing shoe spreading (height of plants >10 cm)	74	5-30	3-20	2-16	76-90
Open-slot injection	78	1-25	1-16	1-13	79-91

Incorporation spreading	81	2-12	1-8	1-6	82-87
Closed-slot injection (arable land)	80	0-3	0-2	0-2	80-82
Closed-slot injection (grassland)	83	0-3	0-2	0-2	83-85

* Ammonia (NH_4-N) losses from EU research project ALFAM end report (ALFAM report, 2001) and Huijsmans Doctoral Thesis (Huijsmans, J.F.M. 2003)

Table 3.51. Cattle slurry handling cost plus cost caused by the ammonia loss by different spreading technologies

Spreading technologies	Slurry handling cost, € ha^{-1}	Ammoniacal-N loss*, %	N loss, kg ha^{-1}	Cost caused by the additional N-fertilizer, € ha^{-1}	Handling + N loss, € ha^{-1}
Broadcast spreading	66	34-100	13-39	10-30	76-96
Broadcast spreading, incorporation during 12 h	66 + 18	26-79	10-31	8-24	92-108
Trailing hose spreading	84	20-80	8-31	6-24	90-108
Trailing hose spreading, incorporation during 12 h	84 + 18	8-32	3-12	2-9	104-111
Trailing hose spreading (height of plants >10 cm)	84	8-50	3-20	2-16	86-100
Trailing shoe spreading (height of plants >10 cm)	88	5-30	2-12	2-9	90-97
Open-slot injection	92	1-25	1-10	1-8	93-100
Incorporation spreading	95	2-12	1-5	1-4	96-99
Closed-slot injection (arable land)	93	0-3	0-1	0-1	93-94
Closed-slot injection (grassland)	96	0-3	0-1	0-1	96-97

* Ammonia (NH_4-N) losses from EU research project ALFAM end report (ALFAM report, 2001) and Huijsmans Doctoral Thesis (Huijsmans, J.F.M. 2003)

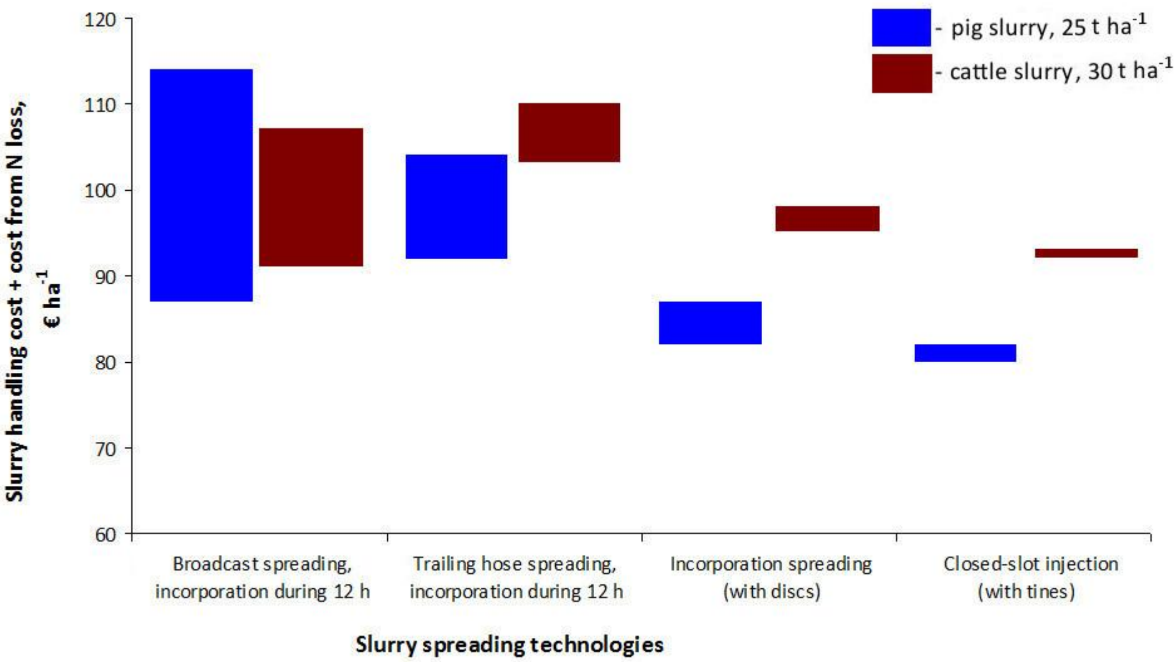

Figure 3.39. Sum of the slurry handling cost plus cost from N loss by spreading to arable land

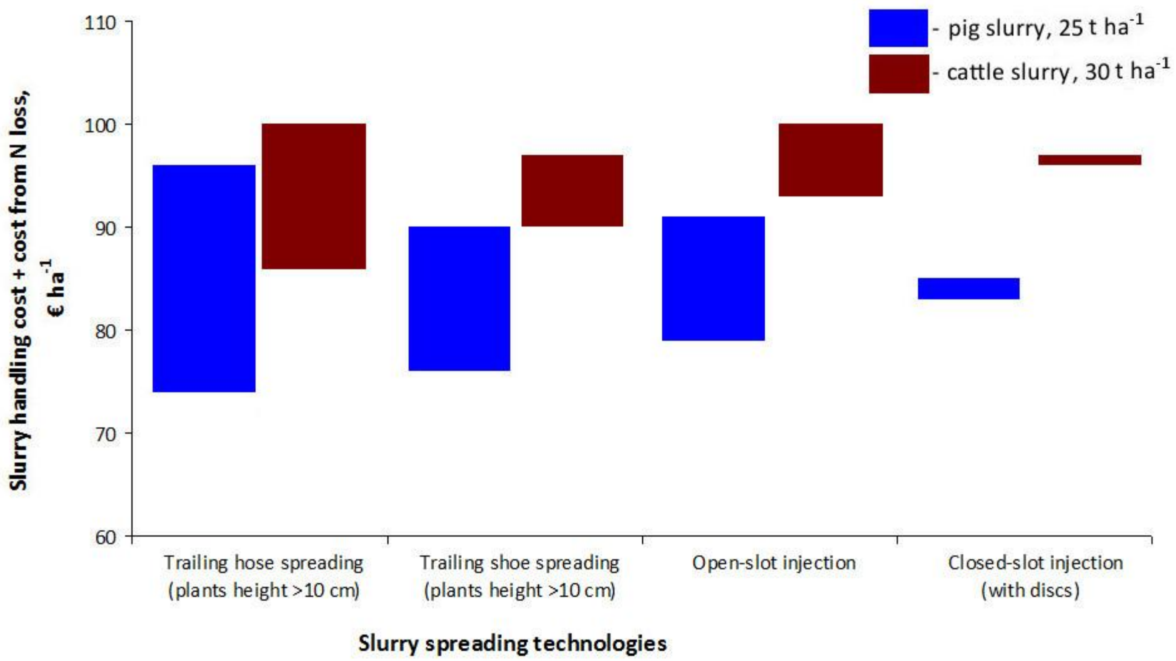

Figure 3.40. Sum of the slurry handling cost plus cost from N loss by spreading to grassland land

3.4.4 Payoff period of slurry spreaders

To calculate the payoff period, the cost of a new spreading technology is compared with existing one.

The presumptions are that:

- The manure type on the farm is slurry. The slurry has to be spread not sold or given away from farm. There is no sense to compare slurry with a fertilising system based only on mineral fertilisers, as in such case it is a crop production farm, where the alternative is to buy manure and spreading from a service provider.
- The yield level does not change with changes of technology. It means that the amount of nutrients given to the soil is same for all technologies. The manure amount is same for all slurry application technologies. Because of thism the amount of nutrient elements is the same except for the ammonium nitrogen (NH_4^+), which is influenced by application technology.

Thus in present calculation:

1. The old technology to compare with is broadcast spreading;
2. The new one, for which the payoff time is calculated, is (a) trailing hose, (b) injection or (c) incorporation spreader with tractor;
3. The slurry application rate for all technologies is 30 t ha^{-1} for cattle slurry and pig slurry 25 t ha^{-1};
4. The cost for mineral fertiliser and cost of spreading of the mineral fertilising is added to the broadcast spreading costs. Mineral fertiliser amount is calculated to compensate nitrogen lost with ammonia emissions.
5. The cost of tillage for slurry incorporation is added to broadcast spreading costs if calculations are made for incorporation spreading as new technology.

Calculated are:

1) A= the cost of broadcast spreading + costs to add mineral fertilisers, € $year^{-1}$
2) B= cost of new technology, € $year^{-1}$;
3) Decrease of costs C=A-B. This is the cost difference coming from usage of new technology, € $year^{-1}$.
4) If the difference of costs C is positive then

T = M / C,
where
T is payoff period, years;
M is the price of new technology, €;
C is annual cost difference, € $year^{-1}$.

The depreciation of broadcast spreader is not taken into account – it is assumed, that the machine is already depreciated. For new technology the depreciation is also not considered because we can say that with payoff period calculation is actually calculated how fast can be collected money for next machine of the same value.

The calculation and results of the sample dairy farms for variant A

Calculations are made for herding system A – animals over six months old producing liquid manure and calves producing solid manure (most liquid strategy) (Chapter 3.4.2)).

Tabel 3.52. The data of the sample dairy farms used in calculations.

Dairy cows	Young animals	Yearly amount of liquid manure, t	Required land for manure spreading, ha
100	92	3 226	108
300	276	9 678	323

900	828	29 032	968

The old broadcast spreader is sold. The prices for new and old machines are in the table 3.53.

Table 3.53. Prices for new and old equipment

Equipment	Price, €
10 year old 10 m^3 spreader	10 000
New 10 m^3, 12 m trailing hose spreader	56 920
New 10 m^3, 4 m open slot injector	54 040

The price of old machines has subtracted from new prices Thus the investment to machines is the following: trailing hose spreader – 46 920 € and open-slot spreader – 44 040 €.
In the case of travel distances 4 and 7 km the pre-haulage technology is used for trailing hose spreading and open-slot injection technologies, cost of that is correspondingly 1.4 € m^{-3} and 1.5 € m^{-3}. In the case of broadcast spreading, the pre-haulage is used only for 7 km.

<u>Cost for mineral fertilisers</u>. The ammonia emissions are in average as follows: broadcast spreading 70%, trailing hose spreading 24% and open-slot injection 10% (See chapter 2). 30 m^3 ha^{-1} is slurry application rate and cattle slurry contains ammonia 1.4 kg m^{-3}. In the case of the broadcast spreading is the ammonia emission 70%- and N loss with ammonia is 0.7 * 30 m^3 ha^{-1} * 1.4 kg m^{-3}=29.4 kg ha^{-1} . For trailing hose spreading the ammonia emission is 24%- and N loss with ammonia is 0.24 * 30 m^3 ha^{-1} * 1.4 kg m^{-3}=10.1 kg ha^{-1}. And for open-slot injection 10% and N loss with ammonia is 0.1 * 30 m^3 ha^{-1} * 1.4 kg m^{-3}=4.2 kg ha^{-1} (Table 3.54). Thus the N win compared to broadcast spreading is in the case of trailing hose spreading 19.3 kg ha^{-1} and in the case of open-slot injection 25.2 kg ha^{-1}.

Table 3.54. The ammonia win and N fertiliser cost reduction by different cattle slurry spreading technologies

Slurry spreading technology	Ammonia emission in calculations	N loss with ammonia emission, kg ha^{-1}	N win compared to broadcast spreading, kg ha^{-1}	Ammonium nitrate win compared to broadcast spreading, kg ha^{-1}	N fertiliser cost reduction compared to broadcast spreading, € ha^{-1}
Broadcast spreading	70%	29,4	-	-	-
Trailing hose spreading	24%	10.1	19.3	56	15
Open-slot injection	10%	4.2	25.2	73	19.6

The nitrogen content of the ammonia nitrate is 34.4 %., thus the amount of the particular fertiliser applied to field in the case of the broadcast spreading should be 56 kg ha^{-1} if compared with the trailing hose technology and 73 kg ha^{-1} if compared to open-slot injection. The price of ammonium nitrate is 268 € t^{-1} without VAT (http://www.silvaagro.ee/vaetised) [15.02.2016].

The trailer loads the fertiliser bags into the trailer, transports the bags to the field, loads the fertiliser into the spreader and the fertiliser is spread to the field. All these costs are taken into the account plus cost of the spreader travel to the field.

Cost differences and payoff period if trailing hose technology is taken into use (Table 3.55) and if open-slot injection is taken into use (Table 3.56).

Table 3.55. Cost differences and payoff period if trailing hose technology is taken into use instead of broadcast spreading.

Slurry amount, m^3	Average distance, km	Slurry transport	Broadcast spreading, € $year^{-1}$	Trailing hose spreading, € $year^{-1}$	Cost decrease, € $year^{-1}$	Payoff period, years
3 226	2	Spreader	6 936	5 897	1 039	52.7
9 678	4	Pre-haulage	24 819	20 637	4 182	13.1
29 032	7	Pre-haulage	79 554	61 356	18 198	3.0

Table 3.56. Cost differences and payoff period if open-slot injection is taken into use instead of broadcast spreading.

Slurry amount, m^3	Average distance, km	Slurry transport	Broadcast spreading, € $year^{-1}$	Open-slot injector, € $year^{-1}$	Cost decrease, € $year^{-1}$	Payoff period, years
3 226	2	Spreader	7 442	6 402	1 040	49.8
9 678	4	Pre-haulage	26 338	22 323	4 015	12.9
29 032	7	Pre-haulage	84 113	66 589	17 524	3.0

The calculation and results of the sample pig farms

Table 3.57 Data of the sample pig farms used in calculations

Finishing places	Yearly amount of liquid manure, t	Required land for manure spreading, ha
2 000	3 200	128
5 000	8 000	320
10 000	16 000	640

The old broadcast spreader is sold. The prices for new and old machines are in the table 3.58.

Table 3.58 Prices for new and old equipment

Equipment	Price, €
10-year-old 10 m^3 spreader	10 000
New 10 m^3, 4 m incorporator spreader	59 120

The price of old machines is subtracted from new prices. Thus the investment to following machines is following: incorporator spreader – 49 120 €.

In the case of travel distances 4 and 6 km the pre-haulage technology is used for incorporation spreading technologies, cost of that is 1.4 € m^{-3}. In the case of broadcast spreading, the pre-haulage has used only for 6 km.

Cost for mineral fertilisers.

25 m^3 ha^{-1} is pig slurry application rate and pig slurry contains ammonia 2.7 kg m^{-3}.

In the case of the broadcast spreading is the ammonia emission 55% if the slurry is incorporated after 12 hours - and N loss with ammonia is 0.55 * 25 m^3 ha^{-1} * 2.7 kg m^{-3}=37.1 kg ha^{-1}. For incorporation spreading the ammonia emission is 5%- and N loss with ammonia is 0.05 * 25 m^3 ha^{-1} * 2.7 kg m^{-3}=3.4 kg ha^{-1} (Table 3.59). Thus the N win compared to broadcast spreading is in the case of incorporation spreading 33.7 kg ha^{-1}.

Table 3.59. The ammonia win and N fertiliser cost reduction by diferent pig slurry spreading technologies

Slurry spreading technology	Ammonia emission in calculations	N loss with ammonia emission, kg ha^{-1}	N win compared to broadcast spreading, kg ha^{-1}	Ammonium nitrate win compared to broadcast spreading, kg ha^{-1}	N fertiliser cost reduction compared to broadcast spreading, € ha^{-1}
Broadcast spreading, slurry is incorporated 12 after spreading	55%	37.1	-	-	-
Incorporation spreading	5%	3.4	33.7	98	26.3

The nitrogen content of the ammonia nitrate is 34.4 %. thus the amount of the particular fertiliser applied to field in the case of the broadcast spreading should be 99 kg ha^{-1} if compared with the incorporation spreading technology. The price of ammonium nitrate is 268 € t^{-1} without VAT (http://www.silvaagro.ee/vaetised) [15.02.2016].

The trailer loads the fertiliser bags into the trailer, transports the bags to the field, loads the fertiliser into the spreader and the fertiliser is spread to the field. All these costs have taken into the account plus cost of the spreader travel to the field.

Incorporation costs. It is assumed that incorporation is made during 12 h after the spreading of the slurry. It is done with a 175 kW tractor pulling a 4 m disc cultivator with rolls.

Table 3.60. Cost differences and payoff period if incorporation injection is taken into use instead of broadcast spreading.

Slurry amount, m^3	Average distance, km	Slurry transport	Broadcast spreading, € $year^{-1}$	Incorporation spreading, € $year^{-1}$	Cost decrease, € $year^{-1}$	Payoff period, years
3 200	2	Spreader	12 328	6 528	5 800	9.8
8 000	4	Pre-haulage	34 395	18 905	15 490	3.7
16 000	6	Pre-haulage	70 586	36 036	34 550	1.6

Conclusion. The pay-off period of new machinery depends on condition of previous machinery or technology replaced by new machines and what costs can be reduced by usage of new technology.

In present sample farms the pay-off period is shorter if the slurry amount is bigger in the farm. The trailing hose spreader and open-slot injector pay-off time was ca. 50 years in farms with 100 milking cows. In the farm with 900 cows was the period 3 years. Similar is picture is in pig farms, the more slurry has the farm, the shorter is pay-off time for incorporation equipment. In pig slurry is the ammonia content higher than in cattle slurry, ammonia loss is bigger in the case of broadcast spreading and therefore is in pig farms the pay-off period shorter than in cattle farms.

If the situation is in actual farm different compared to sample farms, then the farm have to analyse the pay-off period of new equipment with own parameters.

3.5 Summary about liquid manure application

The Estonian Chamber of Agriculture and Commerce survey results (Chapter 4) show that 60% of slurry has spread by injection or incorporation spreaders (table 4.3). 35% of slurry is spread with trailing hose spreaders and 5% with broadcast spreaders. The table 3.61 shows that technologies used more have lower loss of ammonia. Thus, the farmers are aware about the slurry spreading technologies helping save nutrients for agricultural plants and avoid emitting them to the environment.

Table 3.61. Manure distribution parameters and loss of ammonia depending on slurry spreading technology.

Application method	Land type	Injection depth	Application rate, m^3 ha^{-1}	Loss of ammonia *,%
Broadcast spreading	Arable land	Surface	10–80	34-100
Trailing hose spreading	Grassland, Bare soil Crop shoots	Surface	10-50	20-80
Open-slot injection	Grassland, Crop shoots	2-6	15-20***	1-25
High-pressure injection	Grassland	3-10	10-40	10-45
Incorporation application	Arable land without growing crop	3-8	25-50**	2-12
Closed-slot injection	Grassland, Arable land	5-10	10-40	0-3

* Ammonia (NH_4-N) losses from EU research project ALFAM end report (ALFAM report, 2001) and Huijsmans Doctoral Thesis (Huijsmans, J.F.M. 2003)
** Corn has up to 80 m^3 ha^{-1}
*** If the disc has followed by keel or discs are thicker, then the max rate is 30 m^3 ha^{-1}.

Broadcast spreading devices like splash plates are much cheaper than the other type of the distribution devices, the need for pulling force is lower and the distribution capacity is high. However, the loss of nutrients to the environment is so big that the spreading method is not suggestible and is not Best Available Techniques.

Trailing hose spreading is appropriate to use on arable land before tillage. This is less suitable on the fields with growing crops because there is no possibility to incorporate the slurry. Compared to broadcast spreading the trailing hose spreading divides the slurry more evenly and has smaller ammonia emission. The trailing hose spreading has higher spreading capacity than injection or incorporation spreading, spreader is cheaper and is not sensitive for stones but the soil should have to be tilled as soon as possible to minimize ammonia emission. The alternative is to use acidified slurry, which has about half of ammonia emission, compared to non-acidified slurry. It enables to use trailing hose spreading for fertilising of growing crops and grassland. The trailing hose spreader without nozzles are sold with work width between 6–36 m and prices are between 10 500–128 300 € (table 3.7). The spreaders with nozzles are with work width between 6–24 m and prices are between 28 000–86 900 € (table 3.8). The nozzles and tines help to decrease the contamination of plants with manure and to apply slurry nearer to ground and with more even distribution.

The incorporation spreading merges soil tillage and manure spreading into one operation The ammonia emissions for this method is lower than by trailing hose spreading. The odour of slurry is hardly detectable and the runoff risk from slopes is only with tilled soil. The deeper is the slurry mixed the bigger application rates can be used. Disadvantage is remarkable need for pulling force. If the broadcast tillage device is used for incorporation, then the method is appropriate on land without growing crop. Interrow tillage and spreading is possible if adjustment of tools is in accordance with crop rows and the machines are equipped with devices for precise driving.

- The disc incorporation distributor enables to join stubble tillage and manure spreading to one operation whereby the slurry is mixed with soil and straw evenly in tillage depth and over area. It helps to promote straw decay and germination of weed and previous crop seeds. This device is suitable also to join the green manure incorporation and slurry spreading. The disc device does not pull out stones and they work if distribution of organic matter on the field is uneven. Some overlap should be used and the resonance speed should be avoided by working with disc devices. Work widths are between 3–7.5 m and prices between 19 100–51 500 €.
- Tine incorporation devices. The slurry is directed in front of the tines, which are loosening the soil. Slurry is not distributed so evenly as with disc incorporator. The soil and slurry mixing intensity depends on tine shank shape. Tines tend to pull out stones and they tend to jam if there is too much precrop residues on the field. The advantage is absence of bearings requiring maintenance and they are lighter and cheaper than disc devices. Work widths are between 3–7.5 m and prices between 8 650–76 400 €.

Open-slot injection is used to apply slurry to grassland and arable land with growing crops. The slurry is directed to slots cut by discs. Therefore, the contamination of plants and ammonia emissions are smaller than by trailing hose sprayer. However, the slot stays opened and thus the ammonia emission is higher than by incorporation spreading. Suggestible application rate is up to 20 m^3 slurry per hectare in order to avoid overflow of slurry. There is danger for run-off if slots have the same direction as the slope. The open-slot injector is not suitable on stony and heavy soil fields where the slot cutting is problematic or impossible. Work widths are between 3–8 m and prices between 14 500–76 400 €.

High pressure injectors have rare use. Although most of the slurry is pressured to the soil, then some slurry is still greased on the field surface and it causes contamination of plants and some ammonia emissions.

Closed -slot injectors have the smallest ammonia emission. The odour of slurry is hardly detectable and the runoff risk from slopes is low. Disadvantage is remarkable need for pulling force and small work width. If the slurry is directed deep into the soil then there is bigger danger for leaching of nutrients. The usage is limited by soil properties - not suitable on stony and heavy soils. By the choice of the application rate similar to the open-slot injectors also by closed-slot injectors should of are considered with the slot capacity to avoid overflow of slurry. Work widths are between 3–8 m and prices between 11 000–35 220 €.

- The devices with discs and pressure wheels are used on grasslands where the plant plants are short.
- If cultivator type injector is used, then slurry is directed to 15 cm depth. It enables to use higher slurry application rates per hectare but the disadvantage is high draught requirement and low spreading capacity and unsuitability to use that equipment on fields covered with thick straw or on grassland. The injector can be used on crops with wide row width. Same type of application devices are used on the strip-till fields, where strips for plants are tilled together with slurry application.

Summary about economics of slurry spreading

Table 3.62. The impact of different factors on economics of slurry spreading.

Factor	Impact
Farm size and type	Slurry **Dairy farm**. The calculations were made for farms with 100, 300 and 900 milking cows. If the farm spreader was used to transport slurry form storage to the field then the cheapest slurry handling cost was in farm with 300 cows. The reason is that the slurry amount in farm is rather big already but the transportation distance relatively short. However, if the prehauling service is used, then the bigger is the farm, the smaller is slurry-handling cost. For 100-cow farm is the slurry-handling price so high that less expensive is to use full service (3.5 € t^{-1}) containing mixing, pumping, hauling with transport tankers and spreading on field. **Pig production**. The calculations were made for farms with 2 000, 5000 and 10 000 pig places. Slurry handling was cheapest in biggest farm in the case of direct hauling and prehauling technologies both. If the has 5 000 and 10 000 pig places uses incorporation spreading and prehauling, then the handling cost was lower than full service price (3.7 € t^{-1}). In other calculated condition was cheaper to use full service. The pay-off period is shorter if the slurry amount is bigger in the farm. The trailing hose spreader and open-slot injector pay-off time was ca. 50 years in farms with 100 milking cows. In the farm with 900 cows was the period 3 years. Similar is picture is in pig farms, the more slurry has the farm, the shorter is pay-off time for incorporation equipment. In pig slurry is the ammonia content higher than in cattle slurry, ammonia loss is bigger in the case of broadcast spreading and therefore is in pig farms the pay-off period shorter than in cattle farms. Solid manure

	Beef production. The calculations were made for farms with 30, 50 and 100 nurse cows. Solid manure handling was cheapest in smallest farm because the direct hauling method was used. Smaller farms have shorter transportation distance and thus lower manure handling cost. **Sheep production**. The calculations were made for farms with 30, 50 and 300 sheep. Solid manure handling was cheapest in biggest farm because they had bigger manure amount and small differences between transportation distances had no significant impact on manure handling costs. It can be resumed that direct hauling technology of solid manure in cases if the manure amounts are very small, like in sheep farms, then the costs per manure tonne are bigger if farm is smaller. Although the transportation distances in smaller farms are shorter. If the solid manure amounts are big enough like in beef farms, then the costs per manure tonne are the bigger the larger is the farm. The reason is that for distributing of bigger amounts are larger areas required and then the transportation distances are so long that it rises cost of solid manure handling.
Rate per hectare	The calculations with Estonian data show that spreading with farm average amount 50 m^3 ha^{-1} cattle slurry gives lower cost per cubicmeter than 30 m^3 ha^{-1}. The reason is that then the need for area to spread slurry is smaller and presumable transportation costs are lower. However, the cost of application in Latvia is so much cheaper that it is cheaper also to spread with 40 m^3 ha^{-1}.
Comparision between countries	In Estonia were the costs higher than in Latvia, because 1) Most of equipment is in Latvia cheaper; 2) Slurry amounts were in Latvian sample farms bigger than in Estonian because of different manure production standards per animal. Therefore, the costs are divided on bigger amount of slurry; 3) The application rates are higher, because the rates are not limited with P rate per hectare. Thus, the land need is smaller and thus the transportation distances are shorter.
Spreading technologies	Trailing hose spreaders and open-slot injectors are suitable to spread slurry on grasslands or the fields with crops. Economic calculations show that the trailing hose spreading is cheaper in conditions unfavourable for ammonia emissions. Else, in conditions favourable for ammonia emissions, it is recommended to spread with injection or incorporation technologies. The alternative way is to use slurry acidification.
Use of prehaulage	In calculations show that prehaulage helps to minimise slurry-handling costs. The prehaulage with service provider tank truck was about 0.5-0.6 € m^{-3} cheaper than solution where own spreader itself was used for slurry transportation. In the case of suitable distances and landscape (no disturbing obstacles, roads or settlements) is suggestable to calculate cost of establishing pipe connection as alternative for tank vehicles. To minimise waiting times of spreader and transporter is recommended to use buffer tank on the field. The umbilical system can be used to connect

	buffer tank and spreader. Thus, the spreader can work continuously as long as buffer tank is not empty. The field end where generally spreader tank is loaded is then less overdriven and soil has less compacted. The spreader used with umbilical system is without slurry tank and therefore is soil over whole field less compacted.
Manure type	From technological point of view is suggestible to avoid semi-liquid manure (DM 12-20%) because this is not well pumpable nor heapable and is hard to handle with neither liquid or solid manure spreaders. Therefore, it is recommended to separate semi-solid manure to solid and liquid fractions. If the semi-solid manure is not separated, then universal spreaders with watertight box and rear wall are most suitable. If the slurry has high ammonia content like pig slurry (compared to cattle slurry) then the low-emission spreaders like injectors and incorporators have shorter pay-off time. The reason is possibility to save more nitrogen compared to spreading and delayed incorporation.
Size and number of tanks	The calculations show that if the farm own spreader is used to transport the manure to the field the bigger tanks should be preferred, especially in farm with longer distances to the field. If the prehaulage is used then the required tank sizes are smaller and the farm size has no significant impact on the required tank size. In Estonia the suitable tank size was 10 m^3 and in Latvia 16 m^3

Recommendations

1. <u>Make analyse before investments</u>. Previous examples were conducted accordingly to presumptions. On different conditions results can be (and probably are) different. Therefore, every manager, planning investments to new equipment or establishments, must make analyse precisely according to farm conditions, equipment and structures. It can be done as presented before and results should be critically revised according to results achieved on this report.

2. <u>Calculate possibility to use outsource manure handling</u>. Before making any remarkable investment to machinery cost calculations should be made. Price of the own equipment should be compared with service providers offers. On smaller quantities service is usually cheaper, but be aware about service availability on planned time! Nutrient loss is also important on deciding, whether do spreading itself or outsource the service. When selecting suitable service provider, prefer more nutrient effective technologies. Service providers workload is bigger and therefore their machinery is often more advanced and environmentally friendly. Same applies to workers.

3. <u>Use separate transport tankers for liquid manure road transport</u>. Spreaders are expensive and they should not leave from field just for material transport. Separate transport tankers are remarkably cheaper and these are also more suitable for high speed travelling on roads. According to calculations, separate transport tankers save ~0.5 € m^{-3} compared to spreading unit transport. If fields are arranged favourable and not too far (< 10 km) also pipe transport can be used. But this requires careful analyse, whether material is suitable for long-distance pumping .

4. <u>Use field storage, when allowed, possible and economical.</u> This can be done on both, liquid and solid manure technologies. Especially on liquid manure spreading,

waiting times can be minimized, when transporter unloads to the field tank and spreader loads from it. If field tank can accommodate several loads, then both units can work independently with maximum output. Be aware of soil thickening! Spreading unit will travel same route repeatedly and this affects soil. Hose-feed systems are more soil-friendly because of smaller unit weight, but these require regular-shaped and obstacle less fields for trouble-free work.

Solid manure can also be stored to field on heaps for suitable time. There is certain limitation on legislation, which must be obeyed. Storage area must be located so, that minimum damage to environment will be done. Calculate also nutrient loss over time and try minimizing heaping losses. Nevertheless field storage allows better fleet management and less troubles with road load limits on growing period, direct hauling spreading is often more economical: one less loading operation and smaller overall travel distance (which means less time to transport).

5. Calculate payback time. Payback time should not exceed **10** years. Bigger farms have shorter payback time. On 100 cows milking farm both trailing hose and open-slot injection units have payback time ca. 50 years. On 900 cows farm is time 3 years. Other alternatives (reorganize work, outsource manure spreading, machine cooperation etc) must be considered, if payback time exceeds remarkably 10 years. There is always question, why older machinery is not suitable for spreading. When solid manure wagons can be used longer, then broadcast spreaders for liquid manure are prohibited. Farmers want better nutrient usage efficiency, which is also benefit to environment. There is new technologies on market, which address both issues better, than older units. Therefore, farmers can use liquid manure better on newer machinery; nevertheless, older units can still be mechanically sound. Unfortunately there are regions, where is impossible to reduce payback time within reasonable limits less, than 10 years. To preserve environment and farming on these areas, society must support such activities with subsidies.
6. Plan your crop rotation and field usage to minimize transport distances. Transport makes big share on manure handling costs. Therefore, near-storage fields must be planned for these plants, which benefit from manure most. On certain farms, satellite storages are reasonable investments to fulfil economical, ecological and agronomical requirements.
7. Despite higher spreading rate is economical, be careful not to exceed limits! In Estonia both N and P are limited, in Latvia N is limited. Be careful not to overdose, hence plant nutrient intake vary over growing season.
8. Use nutrient-loss minimising spreading technology but consider farm limits. Farms are different with variable conditions. Hence, solution can be different from neighbors. Spreading costs are not only limiting factor, there can be others. Broadcast spreading is not Best Available Techniques (BAT)!

4 User experiences in Estonia

The Estonian Chamber of Agriculture and Commerce made a survey about liquid manure usage in Estonia. The survey was made in the beginning of 2016 and collected results from 51 cattle and 9 pig farms. Most of farms were in size group with 400–600 dairy cows. The slurry amounts and annual number of spreading days are given in the table 4.1.

Table 4.1. The slurry amounts and annual number of spreading days in survey farms.

Number of animals in farm	Number of farms	Slurry amount spread annually, m^3			Number on days required to spread annual amount, days		
		min	max	average	min	max	average
To 200 dairy cows	7	200	8 000	5 957	10	60	36
200-400 dairy cows	10	8 000	20 000	13 000	15	125	56
400-600 dairy cows	19	12 000	35 000	18 737	27	150	63
600-800 dairy cows	6	7 000	35 000	23 333	27	180	87
800-1 000 dairy cows	5	17 000	50 000	32 800	22	110	68
over 1 000 dairy cows	4	42 000	140 000	78 000	42	145	101
to 750 sows	1	3 000	3 000	3 000	49	49	49
2 000-5 000 pigs	4	5 000	12 000	7 900	19	135	69
5 000-8 000 pigs	1	8 000	8 000	8 000	39	39	39
over 8 000 pigs	3	10 000	120 000	50 667	51	240	162

The number of spreading days depending on slurry amount in farm is graphically shown on figures 4.1. The data cloud shows that the minimum number of spreading days is the bigger the more slurry is in the farm. However some farms with small slurry amounts still using similar number of days like big farms. Obviously the reason is small spreading capacity. The required spreading capacity depending on slurry amount in farm is graphically shown on figures 4.3.

The frequency of spreading days in a range of days is graphically shown on figures 4.2. We can see that 56 (95 %) farms are able to spread slurry within 150 days in year and 41 (70 %) of farms within 70 days. 62 days is average number days for dairy farms and 75 days for pig farms.

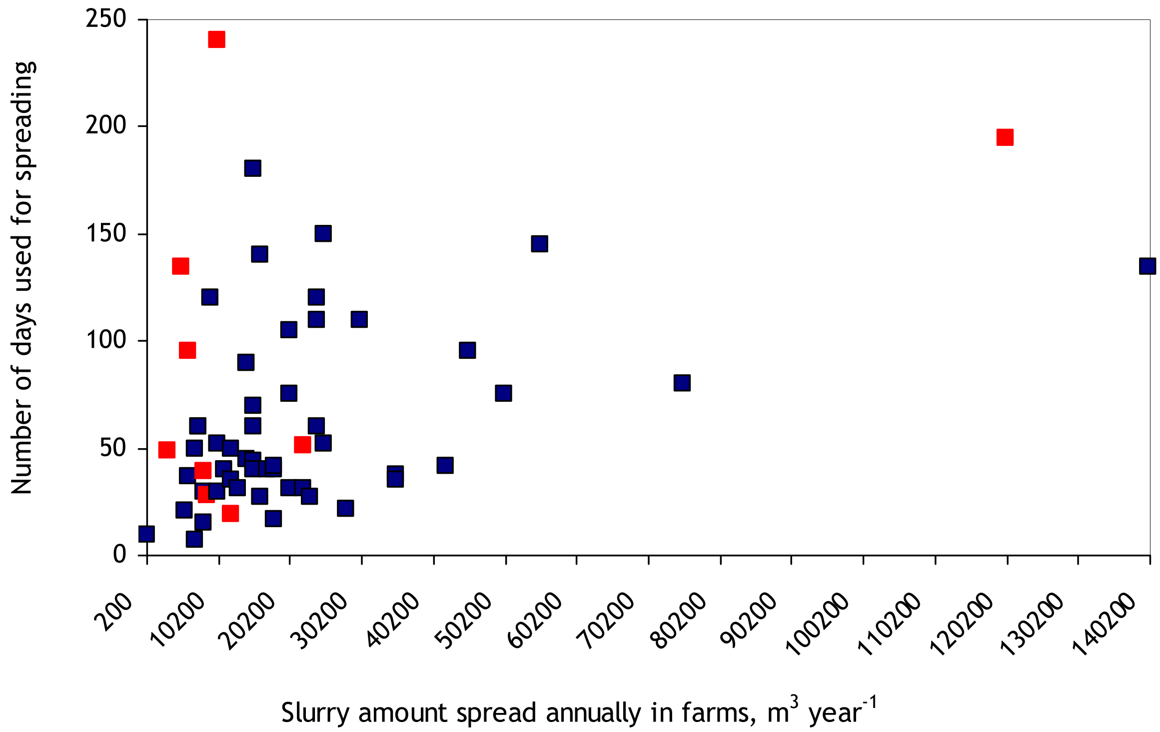

Figure 4.1. The annual number of days required to spread manure depending on slurry amount spread annually in farms (red dots are for pig farms and blue dots for dairy farms)

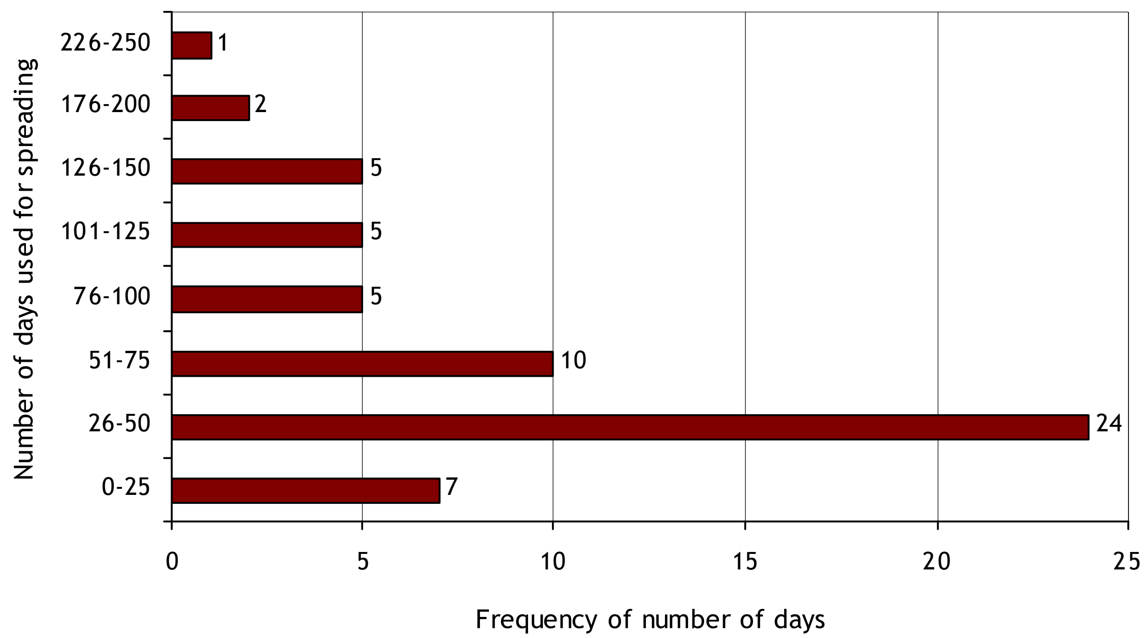

Figure 4.2. Frequency of number of days in survey answers.

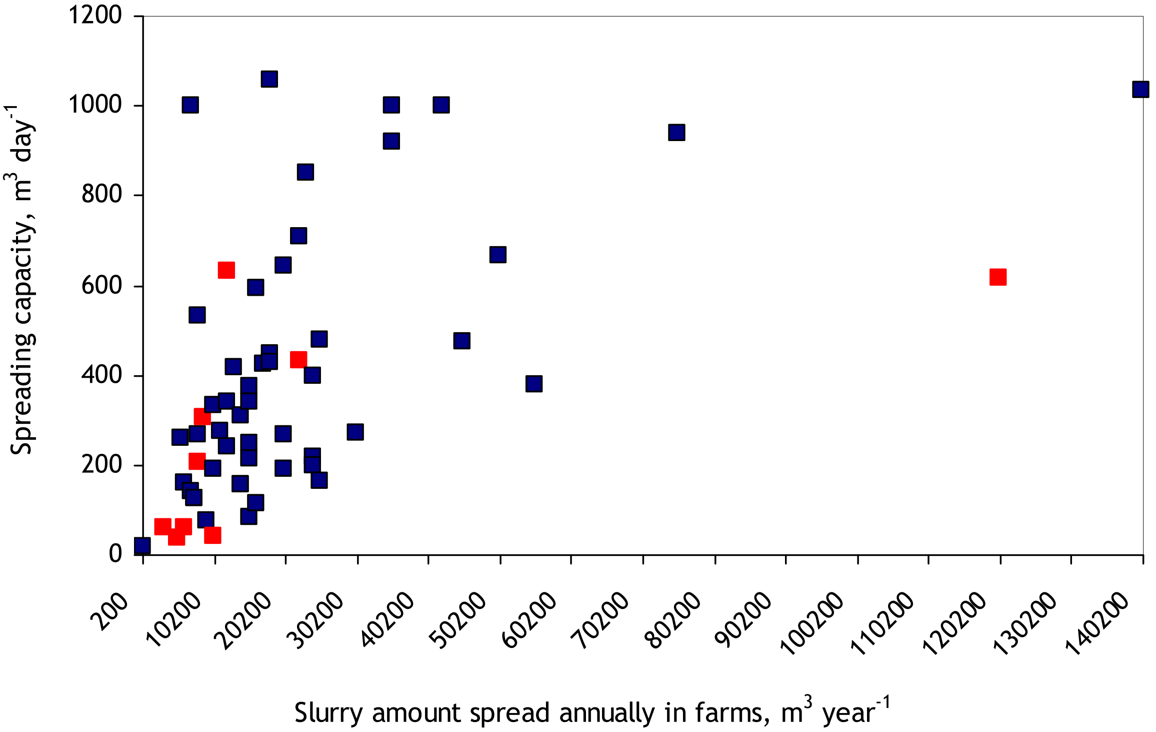

Figure 4.3. Slurry spreading capacity (m^3 day^{-1}) depending on annual amount of manure (red dots are for pig farms and blue dots for dairy farms)

Table 4.2. Spreading technologies, manure amounts and daily spreading capacities in farms

Spreading technology	Number of farms	Annual slurry amount, m^3 $year^{-1}$		Spreading capacity, m^3 day^{-1}	
		min	max	min	max
Broadcast spreading	3	200	12 000	20	240
Trailing hose spreading	14	5 000	120 000	37	632
Injection or incorporation spreading	25	3 000	75 000	61	1 273
Broadcast and trailing hose spreading	2	7 000 7 000	7 500 7 500	214	311
Broadcast and injection spreading	2	4 500 7 200	4 800 10 500	341	343
Trailing hose and - and Injection spreading	9	1 100 4 000	28000 112000	114	1 037
Broadcast, trailing hose and injection spreading	5	2 000 2 000 2 800	6 750 18 000 33 000	156	474

The overview about slurry distribution technologies used in survey farms is presented in the table 4.2. It shows that most farms are using injection or incorporation technologies, smaller part trailing hose spreading and some farms are still using the broadcast spreading.

From whole slurry, 5 % has spread broadcast spreader, trailing hose spreading has used to spread 35 % of slurry and most popular are injection or incorporation technologies with 60 % (table 4.3). By the data from Janis Kazotnieks the 90% of slurry is spreaded by broadcast spreaders in Latvia, the rest is mostly spreaded by trail hose spreaders and some injection devices are also in use. Less than 10 umbilical systems are in use in Latvia. In Estonia, there is not any umbilicial system in use today.

Table 4.3. Slurry amounts spread with different technologies as sum for all farms

Spreading technology	Sum of slurry spread with that technology, m^3	Percentage from total amount in farms, %
Broadcast spreading	65 850	5
Trailing hose spreading	461 400	35
Injection or incorporation spreading	811 050	60

The service provider is used for slurry spreading in 6 0% of survey farm, from which 18 % are not using own spreader at all (table 4.4). Only own spreader is used by 40 % of farms. 55 % of slurry is spread by service providers and 45 % by own equipment.

Table 4.4 Service usage for spreading

Usage of service	Pig farms	Dairy farms	Number of days used for spreading, average (min-max)	Amount of slurry in farm, m^3, average (min-max)	Sum of slurry amounts in farms, m^3
Only service is used	1	10	27 (7–75)	21 191 (5 000–50 000)	369 200
Only own spreaders are used –service is not used	4	20	64 (10–145)	15 383 (200–55 000)	233 100
Own machine plus service is used (part of service 10–90 %)	4	21	85 (30–240)	29 440 (8 000–14 0000)	362 100 service 373 900 own

Table 4.5. shows that 80 % of the smallest farms prefer to use own equipment instead of service providers. In bigger farms is this ratio 40 % or below.

Table 4.5. Number of farms using service provider to spread certain ratio of whole farm slurry

Number of animals in farm	Number of farms	Number of farms where that ratio of slurry is spread by service provider				
		0%	10-30 %	40-60 %	66-90 %	100 %
To 200 dairy cows	7	5				2
200–400 dairy cows	10	4	1	4		1
400–600 dairy cows	19	7	4	3	2	3
600–800 dairy cows	6	1	2		1	2
800–1 000 dairy cows	5	2		1		2
over1 000 dairy cows	4	1	1		2	
to 750 sows	1	1				
2 000–5 000 pigs	4	3				1
5 000–8 000 pigs	1				1	
over 8 000 pigs	3			1	2	
Total	60	24	8	9	8	11

Overview about slurry handling technologies in two Estonian farms.

Estonian farm 1.

The farm has 4 000 ha agricultural land and 2 500 ha is fertilised with manure. The stables with 2 200 dairy cows and 2 000 young cows are producing 130 000 m^3 slurry annually. Calves under 6 month are on bedding and produce solid manure. The slurry is removed from stables with scrapers. The flush system is used only on waiting areas and it is directed to separator. The water amount used for flush is about 2 200 m^3 monthly, partially is used rainwater collected from stable area to underground storage. Dry matter content of non-separated slurry is 5–6%, for separated liquid fraction 3.7% and solid fraction 20%. The liquid fraction is flowing to two lagoons, 50 000 m^3 each and is not mixed before spreading.

The advantage of separated liquid fraction compared to unseparated slurry is better flowability and pumpubility (smaller need for energy), the manure cutting system on slurry spreader is less loaded, the probability for foreign bodies is smaller and risk for jamming of hoses and pipes is also smaller. The more liquid slurry is also infiltrating faster to the soil, from another and the risk for leaching is higher if the slurry is injected to bottom of tillage layer.

The stable has three separators. The solid fraction from two separators is used for fertilising. The solid fraction coming from third separator is composted in drum composter. 200 kg solid fraction is directed to the composter hourly. During composting the temperature is rising up to 65 °C which helps to terminate most of pathogens. The compost is used for bedding of cows. There is no additional bedding material used for cows. The heat from composter heats the rooms where composter drum and separator are placed.

About 53 m^3 slurry per hectare is spread to arable crops and to grasslands being established. Growing grasslands are fertilised with slurry amount of 25 m^3 ha^{-1}. The slurry is not spread onto growing plants. The travel distance from storage to fields is up to 13 km. The solid manure is spread to further fields. Slurry is transported to fields with two tank trucks – 20 and 30 m^3 – belonging to farm. For slurry distribution are available following spreaders:

1. 20 m^3 tank + 4.5 m incorporating cultivator spreader.
2. 20 m^3 tank + 5 m disc injector or 5 m disc incorporator.

The truck tank brings slurry to the field and pumps slurry to the 40 m^3 buffer tank. The spreader sucks slurry from buffer tank to own tank and spreads to the field.

Estonian farm 2.

The farm has 1 790 ha agricultural land and 800 ha is fertilised with manure. The stables with 618 dairy cows and 224 young cows are producing 25 000 m^3 slurry annually. Calves under 6 months and calving cows are on bedding and produce 600 t of solid manure. The slurry is flowing to three cylindrical uncovered slurry storages made from concrete, with total capacity 15 000 m^3. The solid manure is stored in a 4 000 t storage closed from three side (with two slurry storages – 25 and 10 m^3).

The silage storages have 6 storages for silage seepage – 25 m^3, 15 m^3 and 4 X 10 m^3. One of them has continuous overflow system to slurry pump pit.

About 30 m^3 slurry per hectare is spread to cereals, oilseed rape and grasslands 30 m^3 ha^{-1} (corn 40 m^3 ha^{-1}). The slurry is spread to fields up to 7 km from storage. About 40 t solid manure per hectare is used on grasslands being established. For slurry distribution own 12 m^3 tank + 12 m trailing hose spreader is used. Most of slurry is spread by service provider using injection or incorporation spreader and tank trucks for prehauling.

10 000 m^3 slurry is spread by service provider incorporation and injection spreader to the 400 ha on spring during 10 days. Same on summer. 5 000 m^3 slurry is spread by farms own trailing hose spreader to the 166 ha on autumn during 14 days until November 15.

The farm used concentrated sulphuric acid for slurry acidification in March 2015. In one storage 3.2 kg acid per cubic meter of slurry was used and in another storage 3.8 kg acid. The aim was to get cheaper sulphur for fertilising and to decrease ammonia emission. The slurry odour replaced acid odour. There was no notable differences in slurry properties or plants growth.

5 Innovative means from abroad and their usability in Estonia and Latvia

5.1 Slurry acidification

Ammonia loss from livestock manure occurs in livestock houses, manure stores and from the field during application manure. Livestock operations apply various Best Available Techniques (BATs) to reduce emissions, such as air cleaning from the livestock houses, covers on slurry stores, and injection of liquid manure when spreading. Recently, slurry acidification technologies have been developed in Denmark and are approved by the Danish Environmental Protection Agency as BAT (Best Available Techniques) that Danish farms can utilize to reduce ammonia loss by up to 70 %.

Slurry acidification technologies have in Denmark proven to bring real farm level economic benefits in the form of reduced mineral fertiliser consumption and improved crop yields, and are not only expenses for investments and operation. Previous BSR Programme projects including Baltic MANURE and Baltic DEAL recognized slurry acidification technologies as an innovative technology that could decrease nitrogen loss from agriculture in the BSR. However, the commercial use of slurry acidification technologies has not spread outside Denmark.

In March 2016 started a Interreg Baltic Sea Region project “Baltic Slurry Acidification” with full name “Reducing nitrogen loss from livestock production by promoting the use of slurry acidification techniques in the Baltic Sea Region”. In this project are involved also Estonian and Latvian organisations.

The objective of this project is to build upon Baltic MANURE results and promote the use of slurry acidification technologies throughout the BSR. Core activities focus on establishing pilot installations in all BSR countries around which field trials and demonstrations will help to build enduser confidence in these technologies. The project further aims to systematically enhance the capacity of both public and private actors in BSR countries by conducting technical feasibility studies and detailed environmental and economic analyses of slurry acidification technologies implementation. Using these results, together with market and national legislation analyses, the project will formulate policy recommendations for integration of the technology in existing legislation and agricultural support schemes. Expected impacts to the BSR include reduced airborne eutrophication and a more competitive and sustainable farming sector.

5.1.1 Acidification technologies

Ammonia emissions can occur during all phases of the manure handling chain on a farm: during manure collection and removal within the housing systems, storage and land application. In general, ammonia volatilization takes place from the open surface of manure and therefore techniques for reducing emissions often include reducing the surface area from which ammonia can be emitted and controlling environmental conditions (wind and temperature) around the surface area, in housing and storage and during land application. Reducing levels of dietary crude protein in feed has also been shown to significantly reduce ammonia emissions from housing and during storage.

In liquid manure, ammonia (NH_3) and ammonium (NH_4^+) are in chemical equilibrium, where the balance of each is largely dependent on pH. As pH increases, a larger proportion of ammonium occurs as ammonia, which can be lost as a gas. Lowering the pH shifts the equilibrium towards ammonium, which is water soluble and does not evaporate, decreasing the risk of emissions. Around a pH of 4.5 there is almost no measurable free ammonia. Acidification of slurry can therefore be considered a viable technique for reducing ammonia emissions from manure during various points in the handling chain.

Sulphuric acid (H_2SO_4) is highly effective for lowering the pH of slurry and is currently considered the most economically viable additive for acidification. Slurry acidified with sulphuric acid has been shown to significantly reduce ammonia emissions in animal housing systems, during storage, and after band spreading with trailing hoses. Acidification of slurry with sulphuric acid has also been shown to reduce methane (CH_4) emissions from storage of slurry.

Sulphuric acid has a very low pH and is a dangerous product. Strict safety precautions, protective clothing and working routines should always be observed when handling sulphuric acid.

5.1.2 In-house slurry acidification

Acidification of slurry with in-house method reduces ammonia emissions from animal houses, from storage tanks and later from field-applied slurry. Sulphuric acid is used for slurry acidification, at a dosing rate of approximately 5 kg sulphuric acid per tonne slurry. The goal is to reduce the pH value of the slurry from over 7 to about 5.5. The addition of sulphuric acid to slurry generates large amounts of CO_2, which causes a great deal of foaming, and therefore the mixing process must take place in a well-aerated area outside the animal house. This is done in the processing tank (Figure 5.1).

Slurry must first be pumped from the manure channels in the pig shed to the processing tank outside, in which sulphuric acid is added. The pH is continuously measured and sulphuric acid addition adjusted accordingly. Alarms for hydrogen sulphide levels are also integrated. Part of the slurry is then pumped back into the manure channels in the animal house and the rest is pumped to the storage tank (Figure 5.1). The slurry is reverse-pumped in the manure channels, which allows the pH of the manure in the channels to be reduced too.

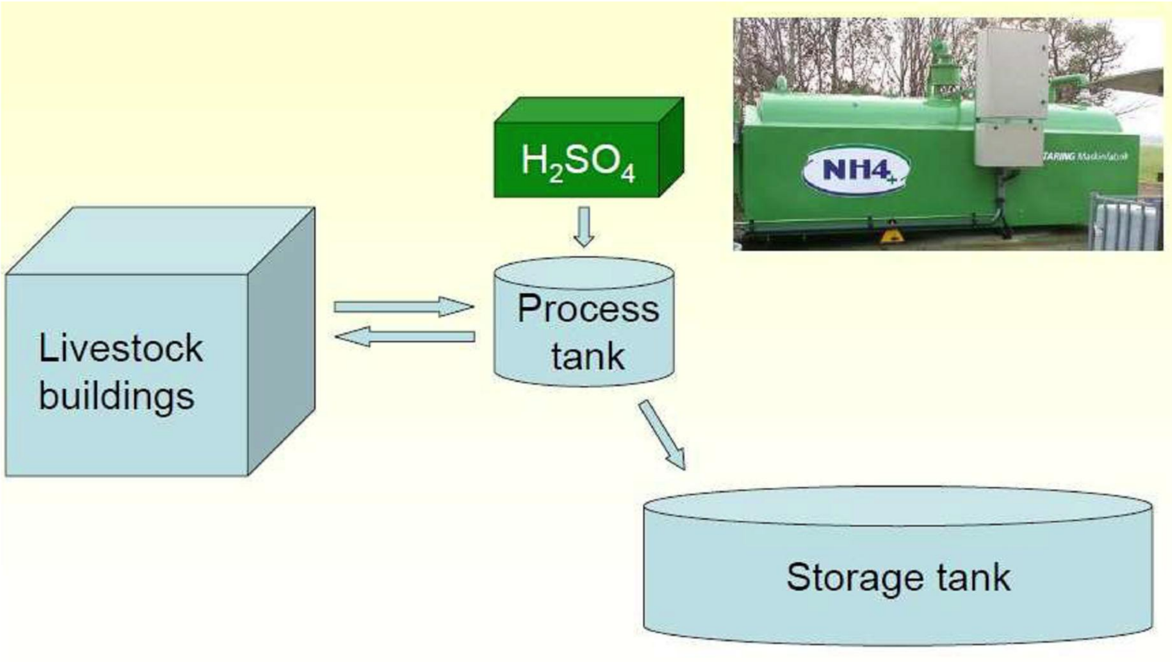

Figure 5.1. Process of the in-house acidification of slurry (Eriksen and Sørensen, 2006).

General investment costs for an JHAgro unit are around 85 000 € for a cattle farm with 6 400 m^3 slurry. Operating costs consist primarily of expenditure on sulphuric acid, electricity and maintenance, with total approximately 6 000 € pear year. Depreciation is calculated 5 000 € per year. The ammonia emission decrease is 51% for cattle manure and 64% for pig manure.

Natural crust covers are generally not well formed after acidification and therefore, in accordance with regulations, there might be a need for an artificial cover for the slurry storage tanks.

Benefits of the acidification system are related to improved N budget on the farm, with more ammonia N in the slurry. Air quality in the pig houses is also improved due to decreased ammonia emissions. In addition, in most cases there is no extra need for sulphur fertilisation.

5.1.3 Acidification of slurry in the storage

Technology for acidification of slurry during spreading, as described in section 5.1.3, reduces ammonia emissions during spreading but misses losses further up the chain. Technology for acidification of slurry in the barn, as described in section 5.1.1, have the advantage of reducing ammonia losses from the animal house, storage and during spreading, however, this can only be used if slurry is stored under slatted floors in the housing system. For the great number of livestock housing systems that do not store slurry under slatted floors, a technology for acidification of slurry before storage could provide a greater reduction in nitrogen loss than simply acidification before spreading. A compilation of ammonia emission factors from Denmark indicated that acidification reduces ammonia emissions by over 80% in storage without cover and by 67% during spreading, as long as the pH is at least 6.0.

Manure has a high buffer capacity which makes it necessary to add relatively large amounts of acid to lower the pH. After acidification, this buffer capacity of manure also contributes to a gradual increase in pH over time, which would in practical terms either limit the time acidified slurry should be stored, or create the need to add more acid over time to maintain the appropriate pH. In one study of in-house acidification of pig slurry in Denmark, acid consumption was between 4-8.5 litres of sulphuric acid per m^3 of slurry. This level of sulphuric acid addition would result in over-fertilisation with sulphur if slurry application rates are based on nitrogen contents.

Currently there are at least two technologies developed for acidification directly in the storage basins. Both technologies add sulphuric acid during mixing of the slurry storage, however with slightly different techniques (Figure 5.2 and 5.3). One adds sulphuric acid from standard IPC tanks (1 m^3), and the other adds sulphuric acid direct from a transport tanker. However, acidification with these techniques is typically performed just prior to spreading so the benefits of reduced emissions from storage are missed.

Figure 5.2. Harsø Maskiner slurry mixing and acidification system (Harsø Maskiner, 2016).

Farm experience in Estonia

In Estonia, there are currently some dairy farms, which acidify slurry in their storage lagoons. One is a dairy farm which produces approximately 40 000 m^3 of slurry, all of which is acidified with concentrated sulphuric acid. The farm has acidified slurry with sulphuric acid for four years now. The farmer orders sulphuric acid with 25 t tank truck and uses 2 kg sulphuric acid per 1 m^3 of slurry. The cost of acid is 130 € per tonne without VAT and transportation. The primary reason behind acidification is that sulphuric acid is less expensive than mineral S fertilizers. The farmer also mentioned the added benefit of reduced ammonia loss, but that was secondary. The pH of the acidified slurry is not measured. The slurry is spread 30 m^3 per hectare with disc incorporator to field before cereals or establishing of grasslands.

The slurry storage is mixed first, and then the sulphuric acid is added into the slurry while mixing continues. There is some foam during acidification but it has not been more than 15–20 cm.

Another farm in Estonia adds acid on autumn to the lagoon half-filled with separated cattle manure. During filling of the lagoon the acid and manure mix themselves and the filled storage is made empty on spring during spreading season.

Figure 5.3. Ørum TF-12 slurry acidification system (Ørumsmeden A/S, 2016). Top left, acid injectors mounted onto a Ørum GMD slurry mixer. Top right, mixing and acidification process. Bottom, Ørum TF-12 rear mounted a tractor with a safety shower and water tank mounted on the front. The sulphuric acid tanker truck is behind the tractor.

5.1.4 Acidification of slurry during spreading on a pig farm

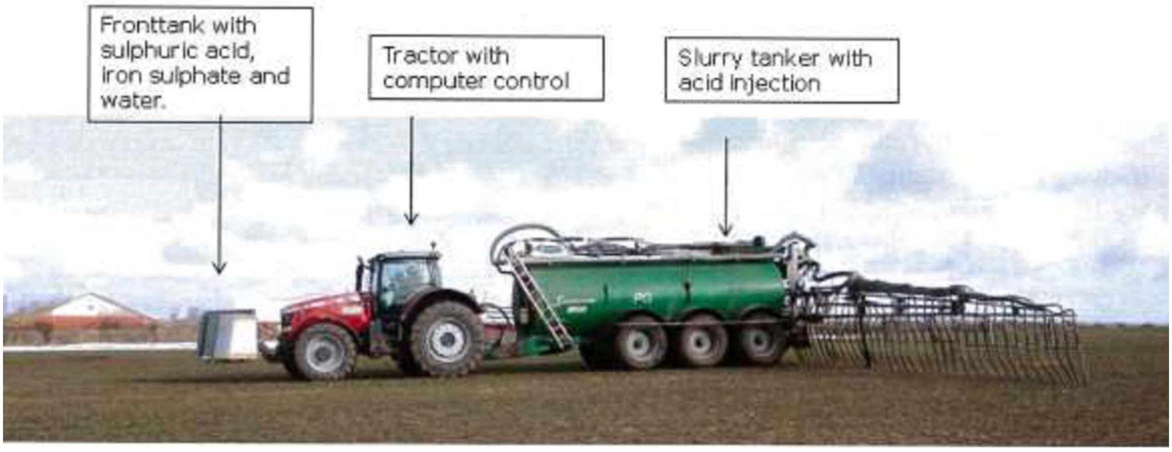

Figure 5.4. The SyreN system for slurry acidification (BioCover, 2016)

The basic principle of the in-field slurry application system is to acidify the animal slurry during land application (Figure 5.4). The sulphuric acid has mixed with the slurry at the back of the tank using a static mixer, which has placed close to the slurry distributor. The static mixer contains solid turbulence elements that ensure effective mixing in just a few seconds (Figure 5.5).

Figure 5.5. The acid injector and static mixing device, which is mounted close to the distributor on the back of the tank (Agrotech, 2012).

Treated slurry goes directly to the hose distributor, which further mixes the slurry and ensures that problems with pressure build-up cannot occur. A pH sensor is placed on the boom before the end of a trailing hose to continually monitor pH and automatically adjust the amount of acid to be added. All controllers for the system are built on ISOBUS standards and use existing on-board electronic equipment.

For example, SyreN is an add-on system installed on existing slurry application machinery, normally consisting of a tractor and a slurry tanker. There are three main parts of the system (Figure 5.6.):

1. Front tanks for storage of sulphuric acid and iron sulphate during land application.
2. Terminal software for regulation of dosage of sulphuric acid and iron sulphate to the slurry tank.
3. Pumps for addition of sulphuric acid and iron sulphate to the slurry tanker.

Figure 5.6. The SyreN-system includes three tanks installed on the front of the tractor. 1) Tank for iron sulphate, 2) site of tank for sulphuric acid, and 3) tank for water for cleaning the system. (BioCover, 2016)

With the in-field system, a wide variety of additives can be added to the slurry together with the sulphuric acid, such as various micronutrients or additives for reducing odour. For example iron sulphate ($FeSO_4$) can be added to reduce hydrogen sulphide (H_2S) which, together with ammonia, is largely responsible for odour problems. Iron sulphate reacts with hydrogen sulphide to produce FeS precipitates and sulphuric acid (H_2SO_4).

SyreN system has GPS/GMS data collection based on CANbus/ISOBUS standards to automatically record amount of acid added, slurry pH before and after acidification, application rate, time, geographical location and more. This makes it ideal for contracting firms and for demonstrating compliance with environmental planning regulations and permits.

Since the acidification processing is performed by a contractor, there are no investment or maintenance costs for the farmer. The cost of spreading the manure is neglected here too, since this cost is applicable even without acidification. On top of normal charges for band spreading with as regards reducing ammonia emissions for compliance with local authority demands, injection of slurry could be used as an alternative to acidification. However, increased draught requirements for application with injection techniques together with small working widths increase the cost of injection compared with band spreading with trailing hose and sulphur fertilisation is still necessary.

5.2 Umbilical systems

The overview about umbilical systems is given in paragraph 3.2.1.

In Latvia one enterprise provides slurry spreading service with umbilical system for following prices:

Up to 3 km (one system), 1.8 € m^{-3} plus VAT plus diesel, which is 0.36 l m^{-3}.

3–5.5 km (two systems)= price for up to 3 km plus 1 € m^3.

Figure 5.7. A umbilical system used by the service provider (Photo: Aragro)

5.3 Measuring nutrients content in slurry

In the Netherlands sampling of slurry from every full tank is compulsory. D-TEC makes it easier for the driver with the MMA- the Slurry Sample Device. This device automatically. taps and packs slurry it into sealed bags The required packaging is distributed by the laboratories. This enables to comply with legislation without compromising on efficiency.

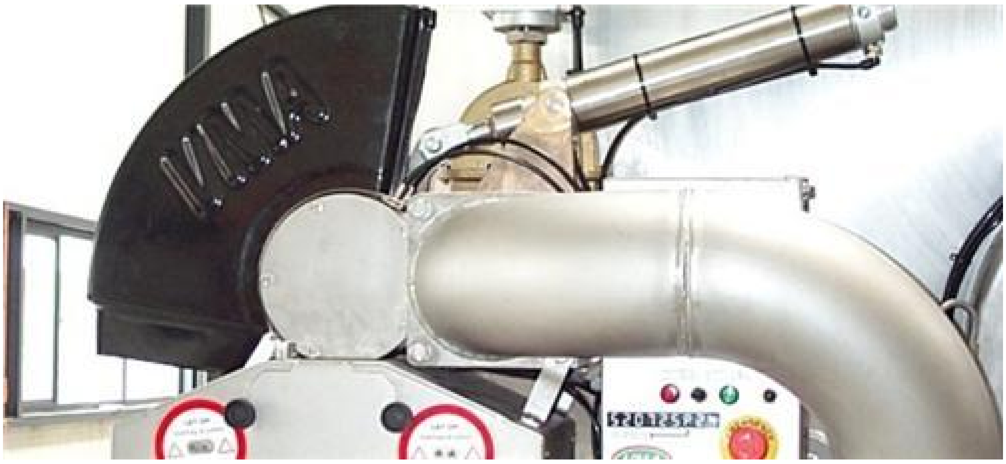

Figure 5.8. The slurry sample device on spreader taps slurry and packs it into sealed bags automatically. (D-Tec, 2016)

The disadvantage of MMA is that farmer gets data some days after spreading. Therefore, most slurry technic producers offer as option a NIR sensor, which has built in the sampling tube of the tank trailer, whereby substance levels in the manure can be determined in real time. This sensor can measure the levels of nutrients including total nitrogen, ammonium, phosphate, potassium and dry matter content in real time. The slurry sensor can be used also on loading pump or buffer tank. If the sensor has mounted on spreader, then the nutrients data are been used to control spreading amount, which makes easier to use precision farming and follow limits for nutrients set in legislation. The sensor data are been documented once per second.

Today the sensor producers are discreet about the precision of measuring. German DLG (Deutsche Landwirtschafts-Gesellschaft) is developing test procedure right now to certify slurry sensor systems. D-Tec says that the deviation of 15% for P and 10% for N is possible.

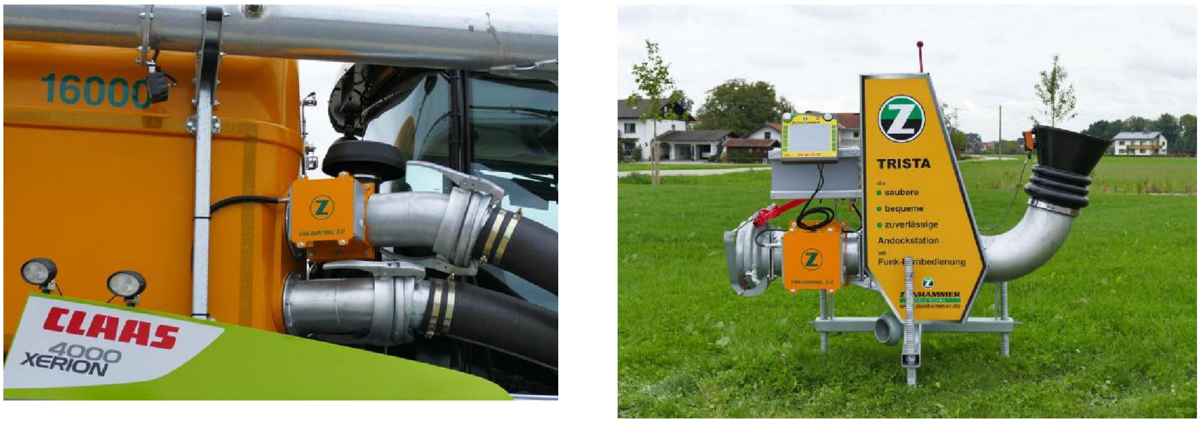

Figure 5.9. The NIR-sensor (Z) mounted on slurry spreader (left) or pump station (right to make real-time nutrient content measuring (Zunhammer, 2016).

The slurry equipment producer Veenhuis offers additional tank mounted on front hitch of the tractor for artificial liquid fertilisers, which can be added to the field according the slurry nutrient content, soil nutrient content and crop nutrient need. The slurry nutrient content can be measured during loading of the tank and spreading. The artificial liquid fertilisers are directly pumped to rubber shoes used to inject slurry into the soil.

Figure 5.10. The artificial liquid fertiliser tank on tractor front hitch (Veenhuis, 2016b).

5.4 Separation of slurry

Separation technologies have the objectives of separating slurry or liquid manure into a solid fraction and a liquid fraction. There may be many reasons for separating slurry. Separation can reduce the volume of the liquid fraction by 15–30% compared with untreated slurry (depending on separator type and efficiency). The liquid fraction generally requires little or no mixing prior to spreading. There is less contamination of crop leaves when the liquid fraction is spread on grassland and, owing to its lower dry matter content, it infiltrates more quickly into the soil after application and reduces ammonia emissions compared with applying unprocessed slurry (Hansen et al., 2005; Amon et al., 2006). However, total ammonia emissions from both the solid and liquid fractions during storage and spreading can be higher than those from unprocessed slurry, depending largely on the storage techniques used for the solid fraction (Hansen et al., 2005). Therefore if separation techniques are used it is important to cover the solid and the liquid fractions during storage. Depending on separation technique used, the liquid fraction can also have a lower P content, since most of the P is bound in organic matter and separated into the solid fraction. This can result in a more balanced N:P ratio in the liquid fraction and allow application rates based on N requirements without exceeding P application limits. The solid fraction, with its much lower water content, has more rational logistic costs for transportation to fields far away. Furthermore, due to its increased transportability, the solid fraction can be exported off-farm as a soil amendment or as substrate for biogas digestion.

Many types of technologies are available for separating manure into solid and liquid fractions. This typically comprises relatively 'coarse' separation, since the separation efficiency of dry matter between the fractions can vary widely depending on numerous factors (Hjorth et al., 2009). Separation techniques can be passive or mechanical. Passive techniques include sedimentation, which can be used for slurries and weeping walls. Mechanical techniques can be more effective, but have greater investment and operating costs. Mechanical separation technologies can include screens, belt press, screw press, centrifuge decanters and flotation or aeration techniques with scrapers. Chemical additives for coagulation and flocculation can be used to increase the separation efficiency of many of these techniques.

Source: Baltic manure 2013. Examples of Implementing Manure Processing Technology at Farm Level. Knowledge report.

Read about separation also in Chapter 4, "Overview about slurry handling technologies in two Estonian farms", Farm1.

5.5 Composting of manure

Composting is an aerobic and thermophilic (40–65 °C) microbial decomposition process that transforms raw organic substrates into more stable organic material, called compost. The composting process is best suited for solid organic matter, although wet composting techniques do exist. Large-scale composting requires oxygenation, regulation of moisture, mixing and substrates with adequate amounts of carbon and N to ensure an efficient process and quality of the compost.

Large-scale manure composting is generally achieved in compost reactors (in-vessel composting) or in windrows (long piles). In-vessel composting with large rotating drums has numerous advantages over windrow composting, since the process occurs in a controlled environment. There is also potential with in-vessel systems to capture gases (primarily NH_3, NO_x and N_2O) generated during the composting process and to clean the outlet air before it is released to the environment.

The composting is used also to process solid fraction of separated slurry. Thank to thermophilic process helps composting to terminate pathogens and weed seeds in manure. The composted dry manure is an odourless fertiliser for nearby residential areas. The composted solid fraction ca be used also as bedding material for cows (See also Chapter 4, Overview about slurry handling technologies in two Estonian farms).

Source: Baltic manure 2013. Examples of Implementing Manure Processing Technology at Farm Level. Knowledge report.

Read about separation also in Chapter 4, “Overview about slurry handling technologies in two Estonian farms”, Farm1.

5.6 Cooling and heat recovery from slurry

The first slurry channel cooling systems on Finnish pig farms were built around 2005. Heat recovered from slurry with a heat pump can produce a substantial amount of the total energy required in a pig house. In addition to slurry, soil, deep wells and inside air can be used as heat sources.

The recovered heat can be used to heat buildings, drinking water or washing water. The main benefit is the savings in heating energy, usually heating oil, although the use of electricity for heating is increasing. Usually, 1 kW of electricity produces 2–4 kW heating energy.

Besides the energy savings, cooling the slurry channels decreases ammonia, methane and carbon dioxide emissions. Due to the reduced emissions, the air exchange rate can be reduced, which means lower heat losses and less odour problems in the surrounding environment.

Under Finnish climate conditions, only part of the required heating capacity can be recovered from slurry cooling. During the coldest winter periods, additional energy for the heat pump has to be obtained from soil, deep wells or inside air. There is usually also an oil or wood chip-based heating system for back-up. Since cooling of the slurry usually only produces part of the required heating energy, a control system for the various heat sources used is necessary.

On one Finnish pig farm, 600 m of heat recovery piping has been installed under a total area of 670 m^2 of slurry channels, meaning about 0.9 m of piping per m^2 of slurry channel area. On this farm (1 000 fattening pig places), 1 200 m^3 of the total amount of 2 000 m^3 of slurry are annually cooled to 12 °C and from this slurry, the heat pump can produce 40 kW heating capacity. The system also contains a 200 m deep well as a heat source, which in summertime is used as a heat sink. The farmer estimates that without the heat recovery system, the yearly heating oil consumption would be 15 000 litres. With the heat recovery system, annual consumption is about 2 000 litres.

Similar results have been reported for another Finnish pig farm using only heat recovered from slurry channels (http://www.environment.fi/download.asp?contentid=139566&lan=fi). The annual slurry production on the farm is about 2 500 m^3 (900 fattening pig places) and the oil consumption per year has dropped from 6 000 litres to less than 1 000 litres. The heating period is about 4 months, from December to March. The electricity consumption of the heat pump is about 8 000 kWh during the heating period. Lower slurry temperature means also less ammonia, methane and carbon dioxide emissions into the house air. This means that if air exchange is not needed to remove heat from the house, the air exchange rate can be substantially lower. Less electricity is thus needed for air exchange and less heat is lost. Cooling the slurry in the house increases the freezing duration of slurry during winter storage, but according to this farm’s experience, this has not delayed spreading. The investment cost for the system with a deep well was about 80 000 EUR in spring 2012. The investment subsidy was 15% and 70% was covered by interest rate guaranteed loan. The heat recovery system from slurry only cost about 20 000 € in 2010, of which about 50% was covered by the subsidy paid for animal welfare.

Source: Baltic manure 2013. Examples of Implementing Manure Processing Technology at Farm Level. Knowledge report.

<u>Conclusion about innovative technologies.</u>

Farmers are interested to direct all nutrients form manure to crops in amounts what plants need. Technology developers offer different equipment to help farmer fill that aim in more and more effective way. This chapter gives short overview about innovative technologies related to manure handling to provide ideas how to improve manure management in Estonian and Latvian farms.

6 Suggestions for effective and environmentally friendly manure handling

Slurry

Arable land with stubble or green manure

During the stubble tillage after harvest it is recommended to add some nitrogen. There is suggestion to give 20-30 kg ha^{-1} N on first tillage after harvest (Väetamise ABC) because plant residue decomposition microbiota is requires also nutrients. More plant residue means higher nutrient demand, especially highly volatile N. In manure should be considered only available ammonium nitrogen. If cattle manure has 1.3 kg ammonium N m^3 and spreading with mixing device results 5% volatilization, then to achieve 20 kg ammonium N rate must be spread 16.2 t liquid manure (30/1.3/(1-0.05)=16.2 m^3 ha^{-1}. To achieve 30 kg N, 24.3 m^3 ha^{-1} must spread. Therefore optimum is between 15-25 m^3 ha^{-1}. Incorporation spreading with disc device is suitable method to join the stubble or green manure tillage and fertilising with slurry into one work operation and to get even mixture of soil, manure and plant residues. The slurry is bound with soil and plant residue particles and the emission of ammonia and odour is low. The slurry is not buried to deep layers and emerging crops sown after some weeks can start to use nutrients from upper layer of soil.

Alternative way is to use trailing hose spreader. However, higher ammonia emissions and need for separate tillage ASAP after application should be taken into account if slurry is not acidified.

Arable land before spring crops

Closed-slot injector with tines is suitable for first tillage after winter if most pre-crop residues are moulded and bigger amounts of slurry per hectare should be applied to build nutrient depot for growing season. Closed-slot injector has very low ammonia emission and in weather conditions favourable for ammonia emission is this equipment most cost effective.

If the field is covered with lot of pre-crop residues and there is risk of jamming of tines then it is suggested to use disc incorporator also in spring.

Alternative way is to use trailing hose spreader. However, higher ammonia emissions and need for separate tillage ASAP after application should be taken into account if slurry is not acidified.

Grasslands or growing crops

Trailing hose spreader and open-slot injector are suitable to fertilise these lands with slurry. Economic calculations show that the trailing hose spreading is cheaper in conditions unfavourable for ammonia emissions (see Weather below). Else, in conditions favourable for ammonia emissions which is often the case for summer days, it is recommended to spread with open-slot spreader. The alternative way is to use slurry acidification. Suggested spreading sate on open-slot injection is 15-20 m^3 ha^{-1}. If device has wider disc carrier or slot-dilate device, then rate may be as high, as 30 m^3 ha^{-1}. Bigger rates may not fit into slot and squirt to ground and plants. In grassland recommendation is spread liquid manure no later, than 6 weeks before cut.

Transportation to the field

The slurry application equipment is expensive and it should be used for slurry spreading as much as possible. For transportation from storage to the field it is cheaper to use separate tank which is not loaded with spreading device and can move faster than spreader. In calculations it was about 0.5–0.6 € m^{-3} cheaper than solution where own spreader itself was used for slurry transportation.

In the case of suitable distances and landscape (no disturbing obstacles, roads or settlements) it may be considered to establish a pipe connection as alternative for tank vehicles.

To minimize waiting times of spreader and transporter, it is suggested to use buffer tank on the field. The umbilical system can be used to connect buffer tank and spreader. Thus, the spreader can work continuously as long as the buffer tank is not empty. The field end where generally spreader tank is loaded is then less overdriven and soil is less compacted. The spreader used with umbilical system is without slurry tank and therefore the soil over the entire field is less compacted.

The amount per hectare

Calculation shows also that 50 m^3 ha^{-1} cattle slurry was cheaper to spread than 30 m^3. The reason is that less land is needed to distribute whole slurry and field distances from storage have been presumed to be shorter. In addition, the work time efficiency is higher because of smaller number of turn on field ends.

Despite higher rates are cheaper unit costs, environmental restrictions must be obeyed. Cost reduction is mainly because lower area requirement for given manure amount, therefore travel distance is also smaller. Less trips means also less wasted time for turning. Another limiting factor is agronomic reasonability, because proper nutrient balance must be achieved with minimum costs. If injection or incorporation is used, there should be no manure in field surface.

Same applies to solid and deep litter manure. Since nutrient content is higher, than on liquid manure, hectare rates are smaller. Example lamb manure consists 1.5 kg t^{-1} P and therefore

Usage of service provider

The payoff period of spreading equipment is the shorter the bigger the slurry amount in the farm. In dairy farm is the payoff period over 50 year for farm with 100 dairy cows for trailing hose spreader and open-slot injector both. In farms with 900 cows the payoff period was under 4 years.

If farmer plans investments to manure spreading equipment, then it is recommended to calculate manure-handling costs in the case of own equipment and compare it with prices with available spreading service providers. For example contracted full service (mixing, pumping, hauling with transport tankers and spreading on field) spreading costs up to distance 6 km are 3.5 € m^{-3}.For smaller farms, the price offered by service provider is often cheaper than usage of own equipment.

The calculations were made for farms with 100, 300 and 900 dairy cows. If spreader was used for slurry transportation then the cheapest was slurry handling in farm with 300 dairy cows. If service truck tank for slurry transportation was used then the bigger is the farm, the cheaper was slurry-handling cost. In the farm with 100 cows was slurry handling so expensive that more cost effective is to use full service.

Semi-liquid manure

From technological point of view is suggestable to avoid semi-liquid manure (DM 12-20 %) because this is not well pumpable nor heapable and is hard to handle with either liquid or solid manure spreader. Therefore, is recommended to separate semi-solid manure to solid and liquid fractions.

If the semi-solid manure is not separated, then most suitable is to use universal spreaders with water tight box and rear wall.

Solid manure

It is advised to spread solid manure with a spreader with vertical beaters and spreading discs. It gives a wider and more even manure distribution than spreaders the horizontal beaters and without discs. It is recommended is to use spreaders with rear walls or doors to avoid manure loss during transportation.

Weather conditions

Humid, windless, cloudy and cool weather is favourable for manure spreading. However, the soil must not be frozen, covered with snow nor over-flooded. Also spreading during heavy rain must be avoided, because of the manure run-off risk.

Suggestions for manure sampling.

Manure sample should be taken from spreading-ready material. If storage will be mixed, sample should be collected after mixing. It must be taken at least from 5 replications, from different locations and layers. Separately taken subsamples should be mixed on suitable vessel. From this one sample is derived, stored in hermetically sealed container at low temperature until analysing. This ensures representative data about nutrient content.

Encouranging use of modern technology by legislation and support schemes.

Legislation and support schemes should emphasize environmental-friendly manure handling technologies usage. This means injection and incorporation technologies or means to soil it shortly after spreading. Farms need machinery, which allows spread manure fast and reliably on amounts needed at best time. This makes nutrients from manure usable to plants and minimizes leaching to environment. Incorporation and injection technologies are effective and should be used more widely.

Contract services availability both for transport and spreading helps smaller farms to exploit manure full potential more effectively with less environmental load.

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