Impacts of heterogeneous manure spreading on nitrate lixiviation

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Introduction

An amount of 150 million tons of animal manure is spread each year in France. The major environmental risk of these applications is the pollution of groundwater by nitrates and France was recently blamed by the European Community for infringement to EC nitrate directive. Improvements of spreading practices are still compulsory. The working of the spreading equipment is currently considered as insufficiently accurate and contributing to heterogeneous applications which may generate diffuse pollutions. In order to assess this problem, we have studied the impacts of heterogeneous manure spreading on nitrate lixiviation. This research project is based on manure application but also wants to consider other organic inputs which may develop now as the increasing prices of mineral fertilizers lead to a new interest for diversified resources.

Several studies on the application qualities of manure spreaders [Malgeryd et al, 1996] have lead to European standards published in the year 2002. They define the spreading distribution requirements for solid and liquid manure spreaders. The requirement levels of these standards have been set up by considering the actual state of the art concerning spreaders manufacturing. It is also an attempt to enhance the performances of this type of equipment considering that the standards can be progressively reviewed in order to take into account the technical advancements in progress. On another hand no agronomic justification has been established for these requirements and it is now impossible to state whether they are insufficient or excessive on an environmental point of view.

As solid manure constitutes in France two thirds of the total applied manure quantity, we have based our research project on solid manure spreaders. This type of equipment is, in France, more generally fitted with vertical beaters which are primarily suitable for cattle manure. Tests methods and requirements for these spreaders are defined by European Standard EN 13080 [CEN, 2002]. It must also be considered that the problem of spreading heterogeneity is linked with the whole manure management. For example, a Danish study analyses the improvement of spreading evenness due to solid manure storage (Hansen, 2004). In our study we suppose that optimized agronomical practices are strictly observed and are not responsible for any diffuse pollution.

Evaluation of the spreader distribution evenness

Spreading distribution quality of manure spreaders is separately assessed by longitudinal and transversal distribution. The requirements defined by EN 13080 are different for each ones as indicated in table 1.

Table 1: Requirements for solid manure spreaders distribution

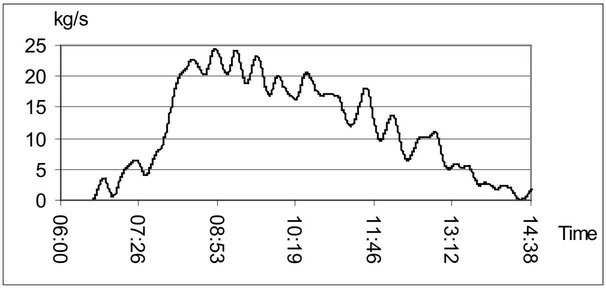
	Transversal distribution	Longitudinal distribution
Coefficient of variation	< 30%	< 40%
Time ratio of correct discharge rate (±15%)		>35%

We may observe that the requirements for longitudinal distribution authorize unsteady deliveries, with high or low values, during 65 % of the spreading period. With this type of equipment, the discharge rate frequently decreases all along the spreading period. This phenomenon is due to the collapsing of the manure heap inside the spreader box. The quantity of manure extracted from the spreader depends on the heap height and therefore diminishes all along this unloading period.

Each coefficient of variation (transversal or longitudinal distribution) will contribute to the global spreading quality. On an agronomical point of view, there is no reason to distinguish these two criteria. It was necessary to set up a specific method enabling to simultaneously consider both distributions. We have therefore defined three classes of spreaders qualified as "bad", "medium" and "good".

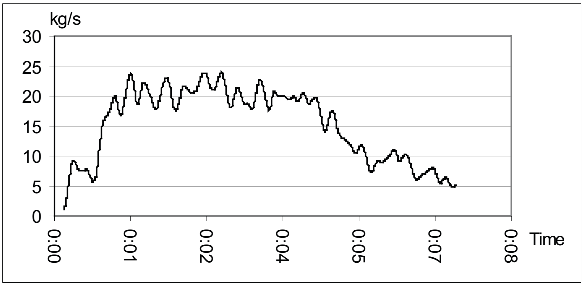
The "bad" spreaders do not fulfill the EN 13080 requirements. This may be the case for a large number of spreaders built at the beginning of vertical beaters development. The first spreaders fitted with vertical beaters were designed in Denmark. As this equipment appeared to be particularly suitable for cattle manure, many manufacturers have introduced this type of spreaders in there range of products without achieving the quality of the initial Danish spreader. The main drawback of this category is a poor longitudinal distribution steadiness as shown on figure 1.

Figure 1: Example of unsteady longitudinal distribution of a «bad» spreader



In this example, the longitudinal coefficient of variation is 55.3% (>40%) and the time ratio of correct discharge rate is only 25.5% (<35%) of the unloading time. Many reasons can explain these results as inappropriate dimensions or placements of the beaters, obstacles to a good manure flow or unsuitable ratio "length/height" of the box.
The "medium" spreaders fulfill the EN 13080 requirements. They are usually fitted with improved beaters and the dimensions of the box have been optimized.

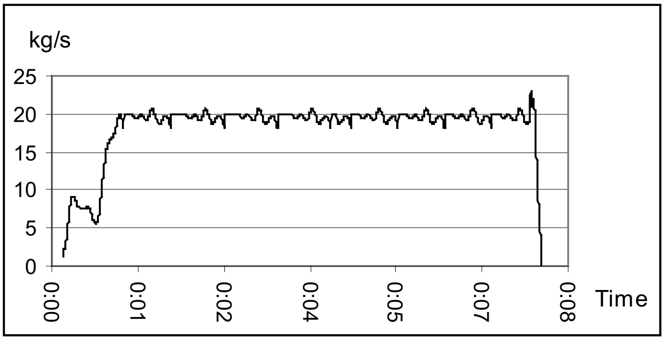
Figure 2: Example of longitudinal distribution of a «medium» spreader



In this example, the longitudinal coefficient of variation is 39% (<40%) and the time ratio of correct discharge rate is 51% (>35%) of the unloading time.

The “optimized” spreader refers to a specific equipment under construction in a French agricultural manufacture. As the fabrication was delayed due to financial difficulties, we do not have tests results at our disposal. However, the working principle and the main parts of this machine have already been experimented so that we can reasonably anticipate the final result. The improvement of the longitudinal distribution is obtained by the means of a front board fastened to the chain conveyor. This front board is not designed to push the manure towards the beaters, but is used to avoid manure collapsing during the unloading time. By this way we can obtain a nearly steady discharge rate. This principle was experimented with success in Italy and a spreader was built with this fitting [Balsari et al, 2000]. In this particular case electronic devices were added in order to adjust the discharge rate according to the forward speed and also in order to measure the weight of the applied manure. Figure 3 presents an assessment of the longitudinal distribution that can be obtained with this type of spreader according to these various sources.

Figure 3: Assessment of longitudinal distribution of an optimized spreader



With such a longitudinal distribution the main factor of heterogeneity will be the transversal distribution. This case is quite similar to the case of slurry spreaders where the discharge rate is quite steady.

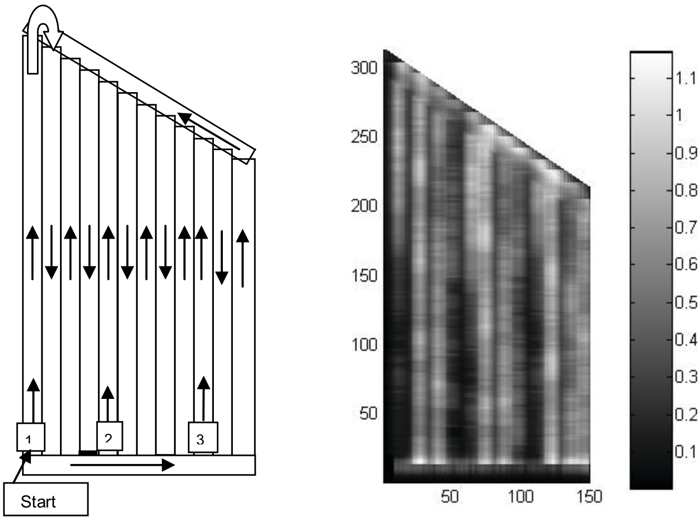
Assessment of the spreading heterogeneity

In order to simultaneously consider both distributions (transversal and longitudinal distributions), we have simulated a virtual manure application on an identical reference field, respectively spread by one spreader of each category. This simulation is based on measured distribution patterns (excepted for the last category) and enables to determine the spread quantity on each square meter of the field.

The area of this reference field is 1 ha (10 000 m^2). The spreader’s route issued from the starting point is calculated according to the spreading width, application rate and spreader capacity. Every time the spreader moves by one step, the quantities measured along the transversal distribution are multiplied by the actual discharge rate indicated by the longitudinal distribution graph. As the distribution tests are run with collecting boxes measuring 50x50 cm, we have used this interval dimension to draw an application map and we have obtained a value for each ¼ m^2. By this way the whole field is covered by a grid which defines 40 000 cells or elementary surfaces.

Figure 4 shows the resulting map for the “bad” spreader. The spreader was filled up three times consecutively. The choice of the starting points was determined according to the farmers usual practices. The field edges are spread at the end of the work. By this way the tractor does not run on the neighboring field.

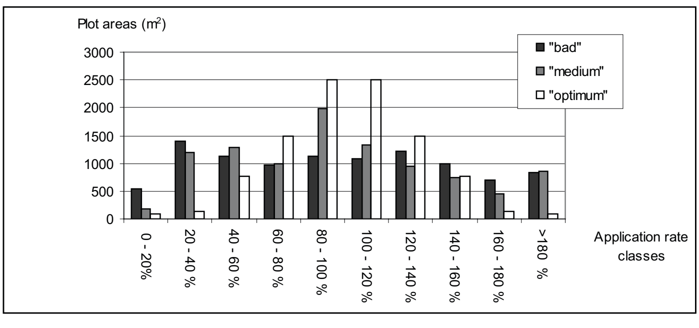
Figure 4: Virtual manure application with the “bad” spreader based on distribution characteristics



Spreader’s route within the field *Calculation of the applied quantity on each cell*

For each application map we have considered ten application rate classes centered on the average value representing 100% of the recommended rate. Any elementary surface will contribute to the corresponding class according to its applied quantity. By this way, the whole field can be considered as the assembly of ten plots receiving a homogenous application rate. The virtual area of each plot is calculated by the number of elementary surfaces included in the plot. Figure 5 represents the area of each virtual plot corresponding to each application rate class for each category of spreader.

Figure 5: Area distribution of virtual homogenous plots for each spreader category



We will suppose that each plot is independent and we will examine the fate of the available nitrogen supplied by the manure application in each case.

Evaluation of the agronomic and environmental impact

Utilization of animal manure for fertilization purposes is difficult to set up. The basic principle is to apply the exact quantity which is needed by the crop. This quantity is usually determined on the basis of regional trials but, because of the different forms of nitrogen found in the manure, the available nitrogen is not precisely known. It depends on various factors as weather, soil, crop and time of application. To solve this problem, farmers use software programs in order to calculate the right amount of fertilizers to be spread. These programs can also automatically edit administrative forms which have to be sent each year to local authorities.

We have used one of these programs, Planfum, for our own specific requirements. Estimated needs are calculated in a first step and a postharvest statement is proposed in a second step:

- The calculation of the recommended rate depends on the crop requirement, the soil type and the secondary effects of previous manure applications. Usually, the manure rate is based on the authorized maximum rate (170 kg N/ha) and the program indicates the corresponding additional rate of inorganic fertilizers which may be applied.
- The global balance of the nitrogen use is calculated after the crop harvesting, when the crop yield is known. The Planfum software also indicates a potential amount of nitrate concentration in the leachates. It indicates whether it is necessary or not to sow intermediate crops (nitrate traps).

Planfum was used to establish the fertilization balance on each subplot of the field and assess the global lixiviated nitrate quantities. The global impact is calculated for the whole field (1 ha). Various scenarios have been studied. Two examples (table 2 and table 3) are presented here corresponding to a sandy soil and wheat crop.

Table 2: Lixiviated nitrate quantities for cattle manure application

Cattle manure (35 t/ha). The available N is 21 kg/ha. The additional inorganic N is 89 kg N/ha

	“Bad” spreader	“Medium” spreader	“Optimum spreader”
N excess	3 kg N/ha	2 kg N/ha	1 kg N/ha
mg NO_3/L	6 mg/l	4 mg/l	2 mg/l
Yield loss	0.08 t/ha	0.07 t/ha	0.03 t/ha

Table 3: Lixiviated nitrate quantities for broiler manure application

Broiler manure (10 t/ha). The available N is 120 kg/ha. No additional inorganic N is required

	“Bad” spreader	“Medium” spreader	“Optimum spreader”
N excess	30 kg N/ha	25 kg N/ha	16 kg N/ha
mg NO_3/L	66 mg/l	55 mg/l	35 mg/l
Yield loss	0.39 t/ha	0.32 t/ha	0.13 t/ha

With cattle manure, most of the nitrogen applied to the crop is related to the inorganic supply. So the differences between the three spreaders categories are very low.

Various experimentations have shown that the nitrate concentrations in the in the drains flow were higher than calculated in the simulation work. The software programs are based on global balances while daily conditions may successively induce excesses and lacks of nitrogen. So these programs do not include punctual concentration peaks. Therefore it should be hazardous to conclude, according to table 2, that the spreading heterogeneity has no impact on nitrate leaching for cattle manure.

With broiler manure, all the fertilization needs are supplied by the manure. An even application at the recommended rate will lead to a small excess of nitrogen. This excess will be magnified by the spreading heterogeneity. If the nitrogen supply had been oversized, the heterogeneity would have slightly influence the nitrate lixiviation, as this excess would affect nearly all the plots (including plots with insufficient collected amount). For a balanced supply, the excess will only affect the plots corresponding to more than 100% of the recommended rate. So an even application will produce less lixiviation than a heterogeneous one.

Conclusion

The simulation of the virtual spreading on the reference field has shown wide differences on spreading heterogeneity for the three spreader categories. These wide differences are not directly contributing to the nitrate lixiviation. The influence of the spreading heterogeneity globally decreases when the application rate is oversized. On the other hand, the influence of the spreading heterogeneity increases when the manure shows a high concentration in available nitrogen.

Finally present requirements of EN 13080 can be stated as “reasonable” for cattle manure, but are insufficient when using highly concentrated organic products like some composts, broiler manures or sewage sludge. Fore these products which may be used as a substitute to inorganic fertilization, the spreading requirement for spreaders distribution should be similar to those established for mineral fertilizers.

The study of environmental impacts linked with technologies is a well appropriate method for eco-design needs based on multi-criteria analyses (LCA, Life cycle analysis). The research and development objectives in farm machinery have usually been based on work productivity and spreading evenness. The gaps of improvement may be more valuable in other fields like nutriment sensing, soil compaction or polyvalence and our research shows that environmental benefit of spreading evenness has often be overestimated.
Taking into account all the potential impacts is absolutely necessary to avoid pollution transfers while designing new technologies. An increase of energy demand may for example deserve an improvement in the matter of eutrophisation. LCA will not allow prioritizing one impact category or another but it will enable to appreciate the potential improvement in every category and so will contribute in decision making for research and development in technologies.

Acknowledgments

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