Author-produced version of the paper presented at AgEng 2010 Conference, 6-8 Septembre 2010, Clermont-Ferrand, France

Environmental performance indicators of organic spreading machines

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Abstract

The ECODEFI project aims to evaluate environmental effects of organic product spreading according to several ways of application. The objective is to improve the global spreading process. The evaluation of the environmental impacts generated by organic product spreading is obtained from Life Cycle Assessment (LCA). LCA uses industrial and agronomical databases but the LCA agricultural machinery database is not well adapted to French spreading machines. The task consists in defining relevant indicators specifically for spreaders of solid and liquid organic product and in measuring performances of commercial spreaders. The indicators are spreading parameters (regularity of the distribution, working width, respect of the application rate, edge spreading), soil impact (compaction, area, and wheel pressure), performance (energy consumption, capacity, and efficiency), and human adaptability (handbook, setting, safety). The representation by radar shows each indicator before and after improvement on the machine.

Keywords: Environmental Performance Indicator, Organic Spreading Machines, Agricultural Machinery

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Introduction

Environmental impacts caused by agriculture are usually associated with the practices (fertilisation, crop protection) implemented in production systems. Generally, this notion is only based on an agronomic point of view. For example, the fertilisation process is built according to plants nutritional needs. Therefore, an environmental impact results of an eventual error of spreading (Piron et al. 2009). This simplistic approach does not take into account all the elements impacting these practices, in particular the role of the machine in the spreading process.

The French program ECODEFI, supported by the French National Research Agency (ANR), aims to evaluate the impact of the global spreading process of organic product. The goal of this project is to establish comparisons between the spreading of liquid and solid sludge from a global environmental impact point of view. The method used to assess the global impact on environment is based on the Life Cycle Assessment (LCA). This method (Pradel et al. 2008) is commonly used in the industry but its use in agriculture needs to get data representative of spreading machines used in France as LCA database currently refers to spreading machines adapted to the Swiss context. The aim of this work is to establish references about environmental performances of the spreading machines in order to develop a database available for LCA method.

This paper presents a set of technological indicators applied for liquid and manure spreaders on the basis of criteria of environmental protection. It explains test methods and calculation to obtain indicators for each machine in a harmonised way.

The first objective is to create several technological indicators to assess the environnemental performance of the organic spreading machines in a global approach, and to use them within LCA method to assess environmental impacts of spreading operations. The second objective is to establish cartography of each technological indicator for each machine in order to compare them or to compare each indicator of the same machine before and after implementation of an "eco-design" process on the machine.

In a first step, an inventory of existing environmental performance indicators for the manure spreaders and slurry tankers has been made and new indicators created.

In a second step, we propose several experimental protocols so as to collect the data needed for the indicator calculation.

Finally, we test these indicators with standard machines and validate them. We obtain an "environmental note" for each machine represented by a diagram of environmental performances. This representation allows the development of a new eco-designed spreader. The test of the eco-designed spreader gives an estimation of the environmental benefice compared to the standard organic spreading machine.

Material and method

Spreaders and organic products chosen for this study

The study extends to organic spreading machines used to spread liquid and solid sewage sludge. Four types of technology corresponding to four spreading devices are chosen.

- Spreading of liquid sludge with injector
- Spreading of liquid sludge in line
- Spreading of liquid sludge with projection
- Spreading of solid sludge with projection

The study framework concerns the research of technological indicators for manure spreaders and slurry tankers in the spreading operation phases including loading/filling up and transport.

For this study, we consider one type of slurry tanker (pressure) with three types of spreading devices (injector, trailing hoses, splash plate) and two types of manure spreader, vertical moving rotors spreader for solid sludge and spreader with discs for pelleted sludge.

Figure 1 presents a schema of the possible environmental risks while using both liquid and solid spreading machines.

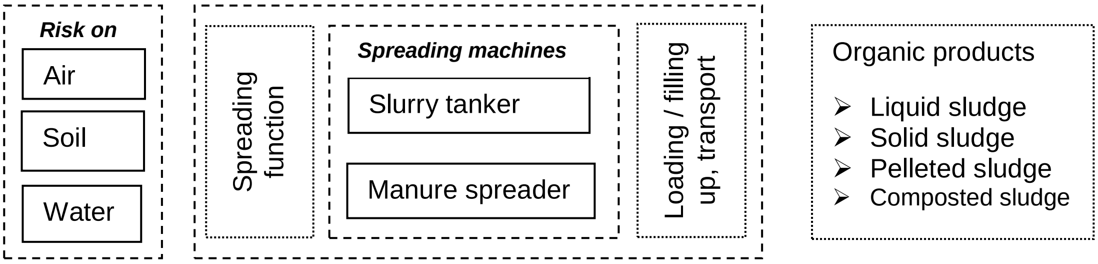

Figure 1: Schema about possible environnemental risk using spreader in sludge spreading.

Method applied to assess environmental spreader performances

In this part, terms and method used are defined in the Ecodefi project to assess liquid and solid spreader in a common way between the project partners (Pradel, 2010).

"Delivered" service function

The "delivered" service function of spreaders expected to meet a need for the spreading operation. For example, the respect of the application rate is one of the identified spreading service function. To ensure this need, several functions can be identified (compliance with the amount applied per hectare, ensuring a homogeneous distribution on the soil, etc.).

Technical function

The technical function is an internal function of the machine (or its components) existing in the studied spreader to assume the service function. For example, the rotor projection assuming internal functions to generate projection speed and to fragment sludge is one possible solution among others contributing to the distribution function.

Performance indicators

The performance indicators aggregate information obtained from technological indicators weighted by a coefficient. As shown in Table 1, the performance indicators varies from case of liquid, solid or line spreading (weight coefficients in brackets).

Example: IR line = (IR1 + 3 IR3 + …………………………….. + IR10) / 14
IR liquid spread pattern = (IR1 + ………………… + 4 IR13) / 26
IR solid spread pattern = (IR1 + ……..…. + IR11 + 4 IR13) / 27

Technological indicators

The technological indicators quantify the level of a criterion on a scale implementation. A score between 0 and 10 defines the level of the indicator for a given criterion. Finally, the score of the machine is calculated for each indicator. The indicator conception is developed in the vein of a harmonisation between the two types of machines (liquid and solid sewage sludge spreaders).
The environment protection standard, EN 13080 for manure spreaders (AFNOR 2003 a), and EN 13406 for slurry tankers (AFNOR 2003 b), define only 3 or 4 indicators in accordance with the preservation of environment. These technological indicators, dealing with transverse distribution (C.V., working width) and longitudinal distribution (Stretch within the Tolerance Zone), are preserved for manure spreader and harmonised for slurry tanker.

Several studies about soil compaction (Diserens 2002) or setting (Rousselet, Mazoyer 2006 a; Cosnier, Rousselet 2005) show that spreading machines provide other impacts. For this reason, we propose to elaborate technological indicators directly linked to the machine and performance indicators related to the spreaders performances in the field (Thirion, Chabot 2003), (distribution quality, application rate accuracy).

In a first step, an inventory of technological indicators for the manure spreaders and slurry tankers, representing different environmental performances, was made. The existing indicators, evaluating machine distribution quality systems and quantifying the distribution, are preserved. These indicators are important to link the impact of fertilisers and those of the machine (Rousselet, Mazoyer 2006 b). New indicators are added in other fields of spreading such as the effects of machine on the soil (compaction) or on energy consumption. A total of 42 technological indicators have been identified (Table 1 and Table 1').

Environmental performance indicators	Technological indicators		Liquid			Solid
			Injectors	Lines	Spread pattern	
Distribution	Transverse distribution	Symmetry	I_{R1} (1)			
		Form of curve			I_{R2} (0)	
		C.V. for working width	$I_{R3L} = I_{R4L}$ (3)		I_{R3S} (3)	
		CV for optimal width			I_{R4S} (3)	
		Strength of C.V.			I_{R5} (3)	
		Border			I_{R6} (2)	
		Cutting of working width	I_{R7} (2)			
	Longitudinal distribution	EZT	I_{R8L} (6)		I_{R8S} (6)	
		Overlapping	I_{R10L} (2)		I_{R10S} (2)	
		Losses				I_{R11} (1)
	Spreading pattern	Spread pattern - quality			I_{R12} (0)	
		Spread pattern - quantity			I_{R13} (4)	
Application rate	Test for obtaining dose		I_{D1} (3)			
	Flow rate setting		I_{D2} (2)			
	Achievement of working width		I_{D3} (1)			
	Quantification of spread materials		I_{D4} (1)			
	Flow rate calculation		I_{D5} (2)			
	Information on the potential of the spreader		I_{D6} (2)			

Table 1: Technological indicators related with environmental performances indicators

Environmental performance indicators	Technological indicators	Liquid			Solid
		Injectors	Lines	Spread pattern	
Fractioning	Fragmentation				I_{F1} (1)
	Blocks				I_{F2} (2)
	Intervals lines	I_{F3} (1)			
Projection	Fines drops			I_{P1} (0)	
	Drop sizes			I_{P2} (1)	
	Projection distance			I_{P3} (1)	
Incorporating – deposit	% of surface materials on the ground (no incorp.)	I_{E1} (1)			
	Deep incorporating	I_{E2} (1)			
	% surface materials on the ground (covered area)		I_{E3} (1)		
Compaction	Pressure load	I_{T1} (2)			
	% packed surface	I_{T2} (1)			
	Deep compaction	I_{T3} (2)			
Rut	Profile rut	I_{O1} (2)			
	% surface rut	I_{O2} (1)			
Power Efficiency	Traction / tonnage on road	$I_{PE1route}$ (2)			$I_{PE1route}$ (1)
	Traction / tonnage on field	$I_{PE1champ}$ (2)			
	Traction injector	I_{PE1enf} (2)			
	Power/flow rate	I_{PE2} (1)			I_{PE2} (2)
	Ha/h	I_{PE3} (1)			
	Polyvalence	I_{PE4} (1)			
Eco	Cleanness	I_{ECO1} (2)			
	Projection width			I_{ECO2} (1)	
	Mass	I_{ECO3} (2)			

Table 1': Technological indicators related with environmental performances indicators

Technological indicators were developed by expertise of spreading specialists and by using results of bench and field tests. Experimentations were jointly conducted by Chamber of Agriculture of Brittany at the Cormiers centre for the slurry tankers and by Cemagref at Montoldre research centre for the manure spreaders.

Experimental protocols for data acquisition for calculating indicators

Distribution and dosage indicators

- Assessment at Cemagref test bench: CEMOB

Experiments were conducted at Cemagref research centre (Montoldre, France) using a bench devoted to organic spreading. The Cemagref organic bench (CEMOB) was developed (Rousselet, Didelot 2007) to improve technological knowledge on how organic spreading machines work. This bench has been designed to carry out transverse and longitudinal distribution at the same time. The test bench is composed of a static platform mounted on weighing devices and motorized beams on which trays collect the organic product discharged by the spreader (Figure 2).

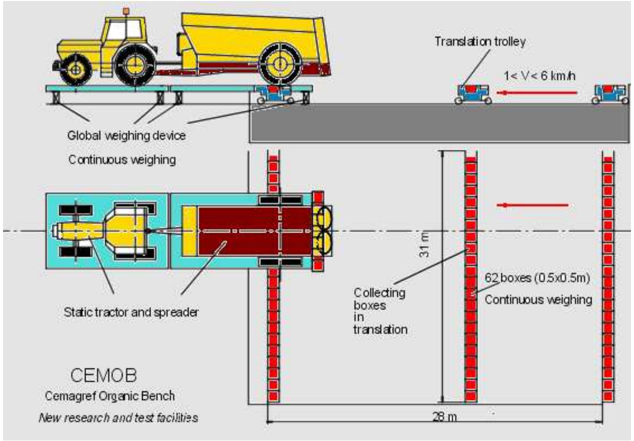

Figure 2: Working principle of the Cemagref test bench (CEMOB)

Each collecting boxes are fitted out with an instantaneous weighing device. Before any test, the spreading machine is identified and the test bench set according to the machine type and spreading parameters. Spreading delivery is determined according to the rate to be spread. During the test, the spreader is placed on the static platform and the organic product is spread while the translation trolleys move. The static platform weighing devices provide data on the spreader discharge by measuring steadily the weight of the spreader. These data are used to produce the longitudinal distribution by calculating a derivative of the spreader weighing discharge.

The collecting box weighing devices provide data on the quantities spread and are used to calculate the transverse distribution as for mineral fertilisers (Piron, Miclet 2005). These data are then analysed and stored by software and reproduced in the form of curves to generate a spatial distribution. This spatial distribution takes the shape of a 3D "spreading pattern" which is the instantaneous transverse distribution profile of a spreader as shown in Figure 3.

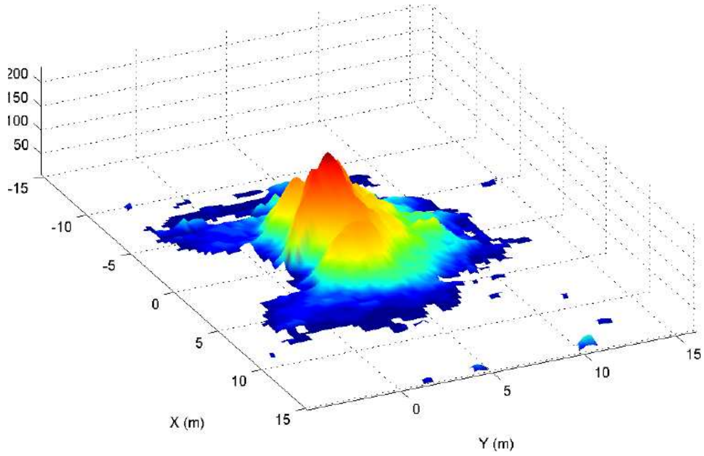

Figure 3: Example of 3D spreading pattern obtained after a test with the CEMOB

- Test bench from the Cormiers centre (Brittany)

The liquid spreader assessments were conducted at the Cormiers centre specially equipped for testing liquid spreader whatever the type of spreading device (splash plate, trailing hoses or injector). The spreader is installed in a fixed position on the platform of the test pit. Each output of the trailing hose or the injector is channelled into a single bin. A hose interface is between the outlet of the spreader and the container measurement. The lower end of the hose is attached to a trolley controlled by five pneumatic cylinders. This trolley allows simultaneous filling up during the same time of each container (Photos 1 to 3).

Photo 1: Spreader at test bench

The spreader is set emptying, in front of the bins, in the gutters to a starting of all output from the device spreading. The operator controls the trolley position of bench test, which brings all outputs simultaneously above their respective bin. The filling up time is 15 seconds.

Photo 2: Detail of test bench for trailing hoses spreader

Photo 3: During the test

The operator runs the program scan scales. The masses of slurry, for bins configured, are collected and stored in a database. The software analyses data, calculates the average deviation and then displays the test report which the transverse distribution curve.

Fractioning indicators

The measuring method used to provide data to calculate fractioning indicator is based on the ESTER protocol from the field test guide for solid organic spreader (Habib 2006). The protocol aims to assess the ability of the spreader to fractioning the spread material. A better fractioning improve the quality of both longitudinal and transverse distribution. The assessment consists in the counting of blocks and stacks using grid of 10 x 10 cm mesh (Photos 4 and 5). In order to inspect the whole spreading pattern, the grid is positioned several times as shown in Figure 4.

Photo 4: Solid sludge spreading on 100m

Photo 5: Position of measure grid on a block after spreading

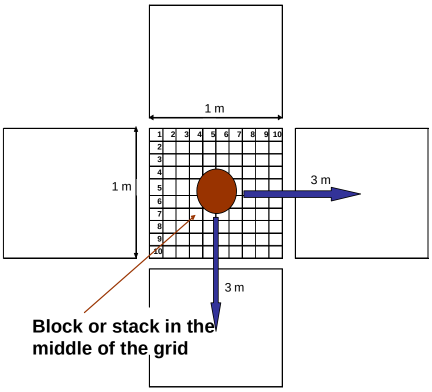

Figure 4: Schema of grid position

Rut indicators

The rut indicator is obtained from the rut left on the ground after the spreader running. To measure the effect of the running of one or different wheel on the soil compaction, the tractor and spreader pass trough a gravel pit (Photo 6). After each passage, the gravel is levelled using a rake. We make also the assumption that the gravel does not undergo compaction.

Photo 6: Gravel pit after passage of spreader

The same measurement principle has been established at the Cormiers centre but, without gravel pit, the profile is developed from traces of tire tracks obtained in a sandbox in the same measurement of the tire tracks area. To trace the profile of the rut, a wooden blade is inserted into the rut and its frame is drawn using a spray paint (Photo 7). The width of track and the rut profile are obtained with this method.

The assessment of wetted perimeter, starting from a simulate water depth of 5mm, and the area of the section in the rut was obtained using the IMAGE J software (Photo 8).

Photo 7: Tracing of rut profile

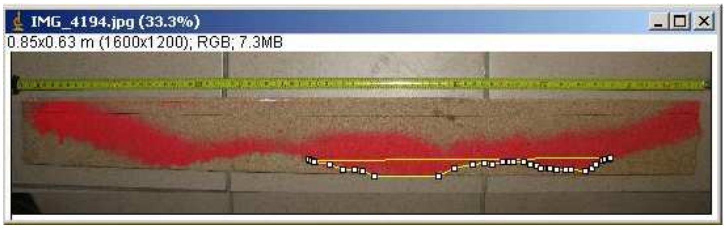

Photo 8: Simulation of 5mm of water in the rut

Compaction indicators

The technological indicators created to assess the soil compaction generated by spreaders are based on three criterions: tire tracks from the machine on the soil, width of the tire and the working width, load per axle.

The load per axle is a data from manufacturer to respect the regulation. For this reason, no specific protocol is developed. However, the load is measured during testing at CEMOB.

Working width is measured during the test carried out for distribution quality and application rate accuracy.

A specific protocol has been established to evaluate the marked surface of the tire. This assessment of the contact surface between soil and tire spreader is made using plaster on hard ground. The plaster is projected to mark the shape of the wheels of the spreader. After moving the vehicle, a photo of the trace is made with a metric scale. Evaluation of the surface and width of the trace on hard ground is measured by using image processing software (IMAGE J). The value of the trace on spreading ground is interpolated taking into account both the value of the trace on hard ground and the value of the trace on soft ground. The width measurements of rut traces found in the gravel pit correspond to soft ground measures (Photo 6).

Power and efficiency indicators

The power efficiency indicators are measured in two sizes (Frick et al. 2001): the power required to drive the machine, and the power to tow the machine.

The indicator of traction per tonnage aims to evaluate the force of traction reported to the towed mass. This effort is measured on a standard soil in a passage on a gravel pit with the spreader in load (Photo 9). A trailer hitch dynamometer allows the measure of the force of traction at 10 Hz. The data processing is done on the average on efforts between the entry in the gravel pit and exit as shown in Figure 5.

Photo 9 Passage of spreader in the gravel pit

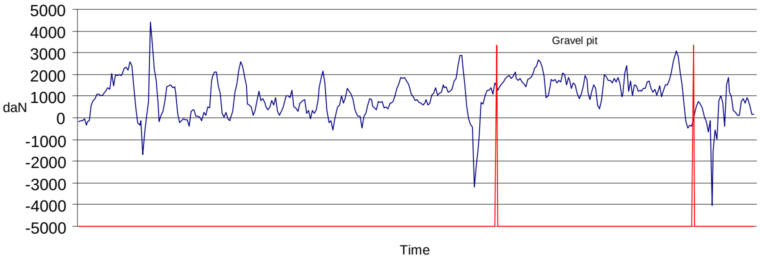

Figure 5: Measure of traction force by hitch dynamometer

The protocol established at the Cormiers centre to evaluate the power consumption is get from torque sensor installed on the tractor PTO (power take-off). This measurement is made along the longitudinal flow measures in order to connect the torque values to those of flow. Data are obtained at the frequency of 10 Hz and stored on computer. Based on strain-gauge technology, the torque sensor uses a telemetry system for the signal transmission. A signal amplifier mounted in the measuring flange amplifies the measuring signal, modulates it to high frequency and transmits it inductively to the receiver. Rotational speed is measured and transmitted simultaneously to display unit. Power is calculated in real time. The measurement system can see the dynamic variations during the discharge of the spreader.

Results and discussions

The indicators in Figure 6 show the differences between a spreader with discs for pelleted sludge and a spreader with vertical moving rotors for limed and composted sludge.

The most important difference is observed for the regularity of the distribution, visible on indicators of distribution, border spreading, losses, spreading pattern and control of working width. These indicators are more favourable to the spreader with discs. It is the same for indicators of longitudinal distribution for the C.V., the overlapping, ability to obtain flow rate and application rate. Significant differences also exist for the compaction of soil with ground pressure lower for discs spreader due to the size and the profile of tires, and the weight of the spreader.

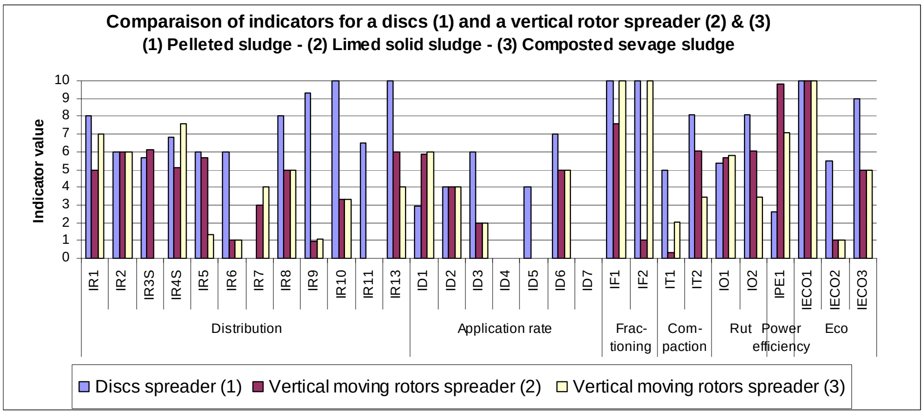

Figure 6: Comparison indicators of disc spreader and vertical moving rotor according to the organic product

The weight of the spreader is lower due to its design. There are also differences between fractioning indicators but also between organic products spread by vertical moving rotors spreader. The indicator mean value is 6 for the discs spreader and 4 for the vertical moving rotor spreader indicating that the rating scale is well calibrated in the mean calculation. We note however that the indicator of cleanness has the maximum value which does not match the image of spreader.

The indicators corresponding to the liquid spreader (Cosnier 2007) are presented in Figure 7 and compare the different spreading devices: a splash plate, trailing hoses and an injector. On this graph, we see that the indicators of longitudinal overlapping, soil compaction, rutting and mass design are identical regardless of spreading devices. The most important difference, linking the indicator of achievement of the working width and the symmetry indicator, appears using the splash plate device compared to the other devices. Other indicators can not be measured because the implementation is very difficult, as is the case of indicators calculated from testing on the field.

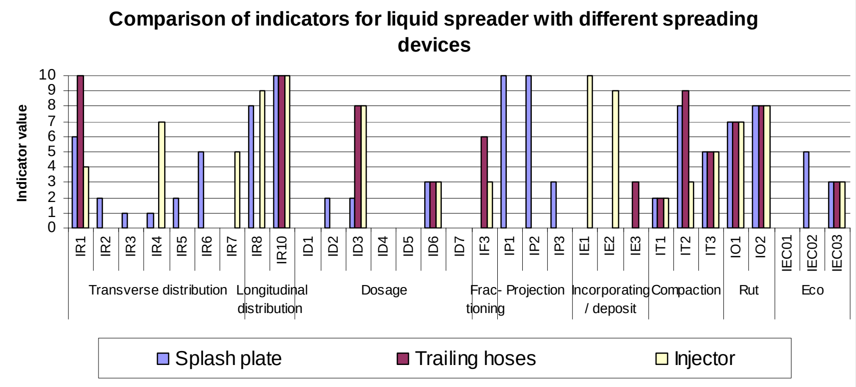

Figure 7: Comparison of indicators for liquid spreader with different spreading devices

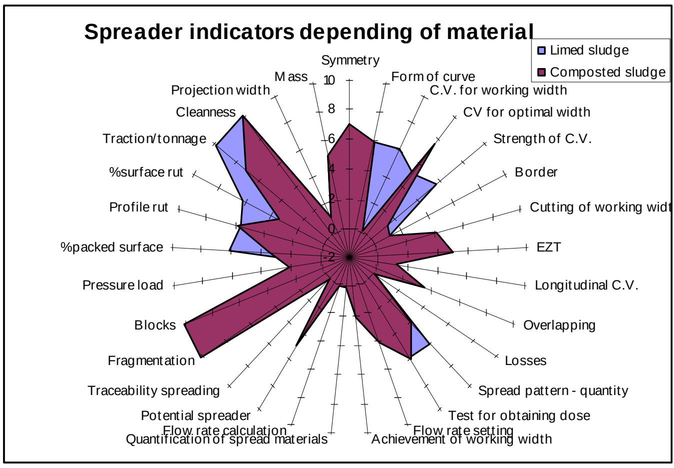

Figure 8: Spreader indicator depending on material

Spreader evaluation can be complicated when the spreader is designed to spread different organic products considering that an indicator is needed for each organic product. This is the case in Figure 8 where the blocks and fragmentation indicators are particularly affected because the spreading device is less effective with limed sludge than with composted sludge. Traction / tonnage and rutting indicators depend on the difference in density of material, distribution indicators of material homogeneity.

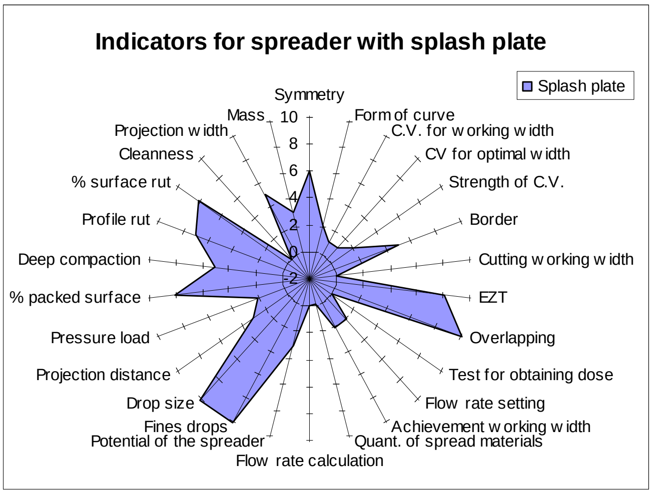

Figure 9: Indicators for spreader with splash plate

Evaluation of liquid spreaders was done separately for each device application. The results obtained for a splash plate device are presented in Figure 9. This graph shows that the indicators of transverse distribution (Form of curve, C.V. for working width, C.V. for optimal width, cutting working width) are low for this type of equipment.

The indicators for flow calculation and obtaining dose also present a low value but the problem is independent of the equipment.

Figure 10 presents the case of a standard spreader compared to a spreader improved in the case of a solid limed sludge application. The applicator has a performance standard longitudinal distribution altered by a large flow variation.

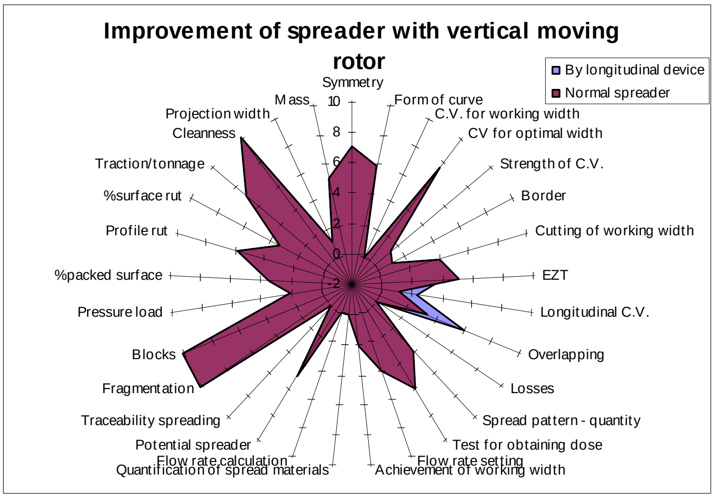

Figure 10: Improvement of spreader with vertical moving rotor

This phenomenon, already found in a study (Rousselet, Mazoyer 2006a, b) with almost all types of spreaders, is one of the major failures to be corrected on the spreaders. The applicator has an improved panel device pusher spreading material to ensure a constant flow of the spreading system. The results show that the improvement was focused on two indicators simultaneously, overlapping and longitudinal C.V. This method of analysis can improve step by step each indicator in a goal of improving the spreader.

Conclusion and outlooks

In this work, a new concept with new indicators has been introduced to assess the environmental performance of solid and liquid spreaders beyond what exists in the standards. Currently, it is considered that this is a methods validation to explain these indicators and use them as an environmental value introduced into the LCA method.

These indicators have been tested on standard machines to validate methods and provide spreaders environmental values. The results show that the value of the indicator depends on the machine, but also on the organic product spread which complicates the evaluation method of the spreader performances. The number of indicators has been chosen deliberately high to meet the needs of the spreader performances evaluation, but too many indicators prevent good interpretation in environmental spreader performances.

The calibration of the method, coupled with the calculation method, shows that the rating scale is correct because the notes well discriminate spreaders and allow possible progresses in spreader design. Small adjustments will be performed for the highest indicators.

The representation of the spreader environmental performance from a performance chart of each indicator is a new approach that allows both comparison of spreading machines and spreading devices of the same type. This representation allows a selection of development priorities for the design of new spreaders. It can also measure the improvement in eco-designed spreader compared to a standard one.

The indicators have been tested in quantities for use in the LCA method. This method will determine the relevance of these indicators and their appropriate amount. The indicators which are not relevant will be removed. Some methods are complicated to implement. If we want to use them routinely, we should review them to simplify them.

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