

Mass flow control for manure spreader

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Abstract

The objectives of this work were to improve the performances of the manure spreaders used by farmers. The principal aim of this paper is to show the chosen way to improve longitudinal distribution of this machinery. A prototype was developed and evaluated in Cemagref at Montoldre. The method consists in controlling the speed of the scraper conveyor regarding the height of the gate during the hopper unloading. The gate is able to follow the product profile. It is technically based on an electronic and automatic adaptation of the scraper conveyor speed in regard with the alimentation section of the beaters and the spreader velocity into the field. For each product, the longitudinal flow rate result is improved according to the EN13080 Standard. Using this technique, the percentage of time spent in the tolerance zone is almost doubled compared to tests without control for the composted products and the longitudinal variation coefficient divided by 2 or 3 depending on the types of products.

Keywords

Manure spreader, mass flow control, longitudinal flow rate curve

1 Introduction

In agriculture, manure, compost, or sewage sludge are generally applied with manure spreaders. These ones are used in farming because of their simplicity, their important transported volume and their general versatility. Today, they are more and more equipped with modern devices which are ergonomic and easy to adjust, designed to make them more efficient in regard with the applied rates. This feature requires the installation of an electro-hydraulic system, especially on the driving circuit of the scraper conveyor. The majority of scraper conveyors is currently driven by hydraulic power. The most advanced feature are piloting by electronic and computer which allow a specific function (Proportional Flow rate in regard with the spreader speed), which uses the control of the scraper conveyor with respect to the spreader speed.

All these functions have a major interest and are really necessary to optimize the spreading with this agricultural machinery. Without these functions, it's impossible to obtain the target rate at each point of the field. However, to ensure a correct running of these devices during spreading, the mass flow criteria must be under control: this is not the case for the majority of spreaders. The current devices can solve problems of slowing or slippage of the tractor. But they don't solve defaults related to density heterogeneities or spreader filling. Moreover, they are not able to adjust the machine settings in function of the applied product.

The mass flow curves recorded on machines equipped with modern electronics show some defects. One of the most significant problems with this type of spreader is the variation of the delivered flow rate during the discharge especially at the beginning and at the end of the hopper unloading. Then, this default involves rate heterogeneity into the field.

Last years, many studies and several devices have been developed to control continuously the mass flow. In particular, the control by the consumed torque on the beaters, the global weighing of the spreader or the weighing of a part of the product just in front of the beaters. Actually, No devices provide entire satisfaction in term of mass flow control.

A correct control of manure application should be based on the coupling of two different devices. The first one is used to solve the defaults at the beginning and at the end of hopper unloading. The second one is used to weigh the product and provide continuously a correct value for the manure volumetric mass to be spread.

The aim of this work is to propose a technical solution combining the use of mechanical adaptations on the spreader and some electronic developments to obtain a greater regularity of the flow rate during the discharge. This method, patented in 2006 by the Cemagref (Piron and Miclet, 2006), has been commercialised by a French society: "Agrotronix". It is technically based on an electronic and automatic adaptation of the scraper conveyor speed in regard with the alimentation section of the beaters and the spreader velocity into the field. This system is adjusted according to the product density, which is continuously measured by several sensors. Firstly, the device regularises the shape of the flow rate curve providing a maximum range of time with a good stability, and secondly, the absolute value of this regular flow rate curve is adapted to obtain the objective rate.

2 Materials and methods

In this study, a base of manure spreader has been used. The selected machine is equipped with two vertical beaters and a scraper conveyor driven by hydraulic. The storage capacity was 6.15 m³ with hopper dimensions of 3.57m length, 1.43m width and 1.3m height. A scraper conveyor takes place at the bottom of the hopper to displace products through the spreading systems. A flow-control gate was placed on the hopper, 0.8 meter far from the vertical beaters.

2.1 The proposition of flow rate control

The variations of the delivered flow rate during the discharge fit with the section variations of the product in front of the beaters. This section is equal to the multiplication of the hopper width by the height of the product. The width of the hopper is constant during the discharge so the only variable parameter changing the product section is the height of product.

Based on this observation, a mass flow control is possible during the hopper unloading by enslaving the scraper conveyor speed ($V(t)$) to the height of the product in front of the beaters ($H(t)$) knowing the height of the flow-control gate.

Then, the conveyor speed is written as follows:

$$V(t) = \frac{F(t)}{\mu(t)} \times \frac{1}{S(t)} \approx \frac{F(t)}{\mu(t)} \times \frac{1}{L(t) \times H(t)} \approx Const \times \frac{1}{H(t)}$$

$\mu(t)$: Product density - (kg.m⁻³)

$S(t)$: Section - multiplication of the hopper width ($L(t)$) by the height of the product

$H(t)$ - (m²)

$F(t)$: Flow rate - (kg/s)

This solution is not new and is already present on some "rate proportional to speed" devices used on sewage sludge application where the value of flow rate is setting by the height of the door. For manure, this adjustment is impossible without wrenching the gate because of the important manure cohesion.

To improve the control working, the system must take into account a chronological delay concerning the gate heights to change the scraper conveyor speed only when the measured

volume of product is really just in front of the beaters. In this way, the conveyor speed is modified at the right time.

Then, the conveyor speed is written as follows:

$$V(t) = \frac{F(t)}{\mu(t)} \times \frac{1}{S(t-t_{dx})} \approx \frac{F(t)}{\mu(t)} \times \frac{1}{L(t) \times H(t-t_{dx})} \approx Const \times \frac{1}{H(t-t_{dx})}$$

$H(t-t_{dx})$: Manure height taking into account the distance between the gate and the beaters (m)

For manures, the technical solution consists in adding a first regulation level. Continuously during spreading, this first control must enslave the height of the gate at the height of the product just in front of the beaters. With this technique, for a desired rate, the scraper conveyor speeds up when the door height increases and slows down when the gate height reduces (Fig. 1.a).

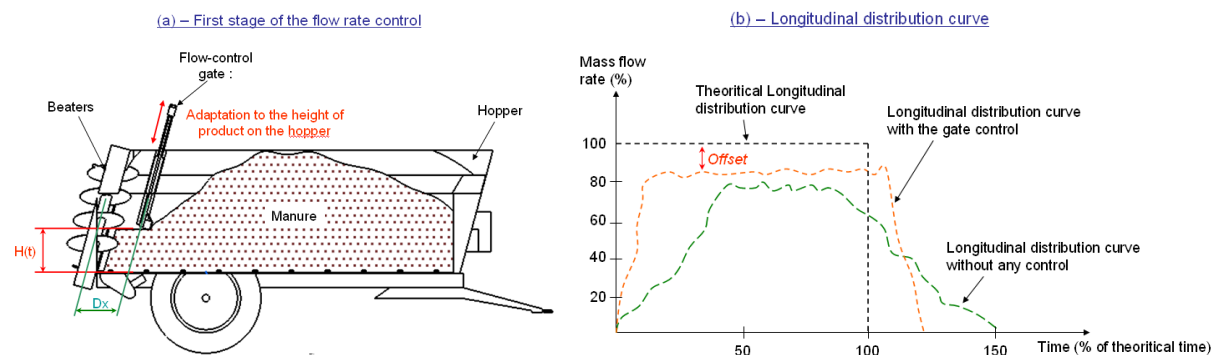


Fig 1: Description of the first stage of the flow rate control.

- (a) Adaptation of the gate height to the height of product (during all the hopper unloading)
- (b) Consequence on the distribution curve.

Following the manure profile, the gate generates a flat upper surface in the hopper. Consequently, a good measurement of the product section is guaranteed and the optimal speed of scraper conveyor can be applied by electronic.

This adaptation of the gate height to the product height has a significant effect against manure crumbling into the spreader in direction of the beaters. Until now, the product density is considered as constant even if this criterion is not fixed in the reality. The product density can change (i) during spreading, (ii) from one hopper loading to another (iii) but also from one product to another. The longitudinal curve is close to the theoretical longitudinal distribution curve but an offset is still present between both curves (Fig 1.b)

To improve the results, a second regulation level has to be considered. The spreader weighing is necessary to adapt the volumetric mass factor continuously. Then, the conveyor speed is written as follows:

$$V(t) = \frac{F(t)}{\mu(t)} \times \frac{1}{S(t-t_{dx})} \approx Const \times \frac{1}{\mu(t) \times S(t-t_{dx})}$$

A first weight measurement is necessary just after spreader loading. It allows the volumetric mass calculation of the product taking into account the spreader volume. Then, this weighing measurement does not require a high sampling frequency (0.1 Hz is sufficient). The structure of the machine was equipped with load cells. In this case, the mass information is not used for a closed loop control, but is simply used to continuously calibrate the product density (Fig.

2a). Similar satisfying devices are already used on fertiliser spreaders. They can continuously adjust the product density during spreading.

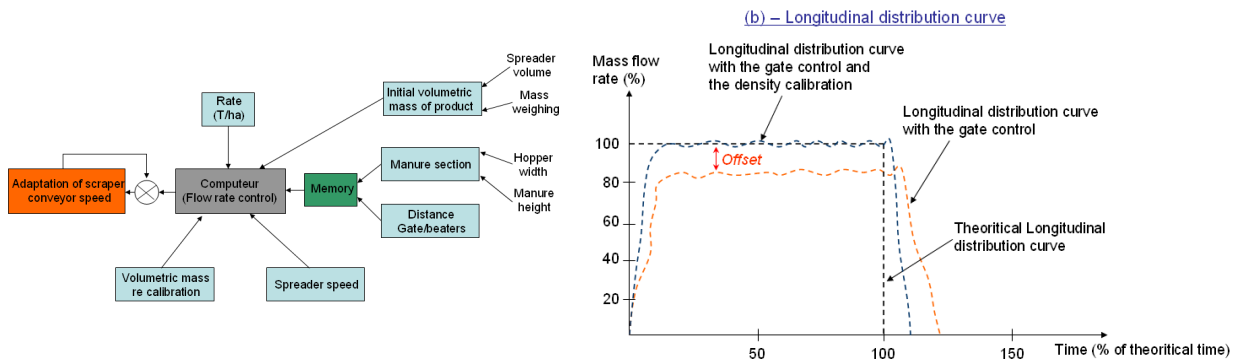


Fig 2: Description of the total flow rate control.
 (a) Schematic description of the control system
 (b) Consequence on the distribution curve.

2.2 Mechanical and electronic adaptation of sensors on the spreader

Some adaptations are done to place sensors on the spreader. All these sensors are plugged on a computer unit (Fig 3.a). This unit is the brain of the system: all sensor signals are read by the unit and all electrical orders are sent by it.

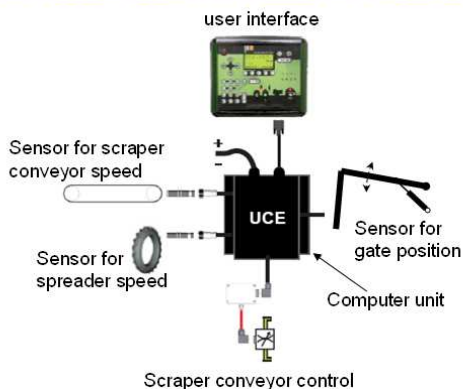
2.2.1 Volumetric flow rate control

The system requires three sensors to ensure the global functioning of the volumetric flow rate:

- One angle sensor with analog output to measure the gate height,
- One numeric encoder to measure the scraper conveyor speed,
- An inductive sensor to measure the spreader speed.

Depending on the type and the configuration of the spreader, other sensors can be installed to obtain similar results.

(a) – Schematic draw of the volumetric flow rate control



(b) – angle sensor for gate height measure



(c) – inductive sensor for spreader speed measure



(d) – numeric encoder for scraper conveyor speed measure

Fig 3: Description of the volumetric flow rate control.

- (a) Schematic draw of the system
 (b) Photography of sensors which are used on the spreader

2.2.2 Gate height control

The opening gate control was based on the continuous measurement of forces induced by the product on the gate (Fig 4.a). Two main solutions were possible: the use of force transducers directly integrated into the gate or the use of inductive sensors included into a mechanical frame placed on the gate bottom. The second solution was chosen because the system was cheaper and more robust to work with products as manure (Fig 4.c and d).

The developed system uses two inductive sensors. Using these sensors, the gate can be positioned at fixed positions, otherwise the gate would only go up or down without providing regular measurements of the height of product during the hopper unloading. The sensors send a binary signal value depending on the force applied by the product on the gate. The use of two inductive sensors allows the same control than the one obtained using force transducers (Fig 4.b):

- When only one sensor is active: No action on the gate and therefore the scraper conveyor speed stays constant,
- When both sensors are active: the gate goes up and the scraper conveyor speed decreases,
- When both sensors are inactive: the gate goes down and the scraper conveyor speed increases.

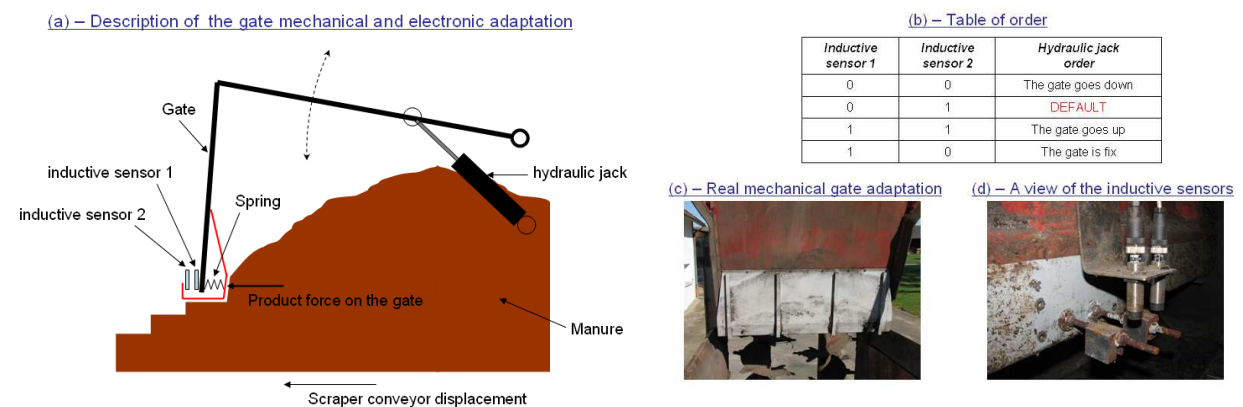


Fig 4: Description of the gate control.

- (a) Description of the gate and electronic adaptation
 (b) Table of hydraulic jack order for the gate control
 (c) Real mechanical gate adaptation
 (d) A view of the inductive sensor used

2.2.3 Product density calibration: The weight measurement of the spreader

The density calibration is possible by the strain gages addition on the spreader mechanic frame. With this type of weighing, the delivered signal accuracy is enough to know the mass of applied product. The mass difference is calculated between two instants spaced of 10 seconds. The mechanical noise generated during the spreader displacement in the field is not a major problem because the signal is filtered on a significant period. In this case, the mass information of load cells is not used for closed loop control but only for a continuous density calibration.

The installation requires three strain gages placed on the spreader frame at each support point: two on the wheels axis and one on the coupling (Fig. 5). This weighing system can be

placed on a spreader without any modifications: the developed device doesn't require a dual mechanical frame (which is very costly) to insert the load transducer.

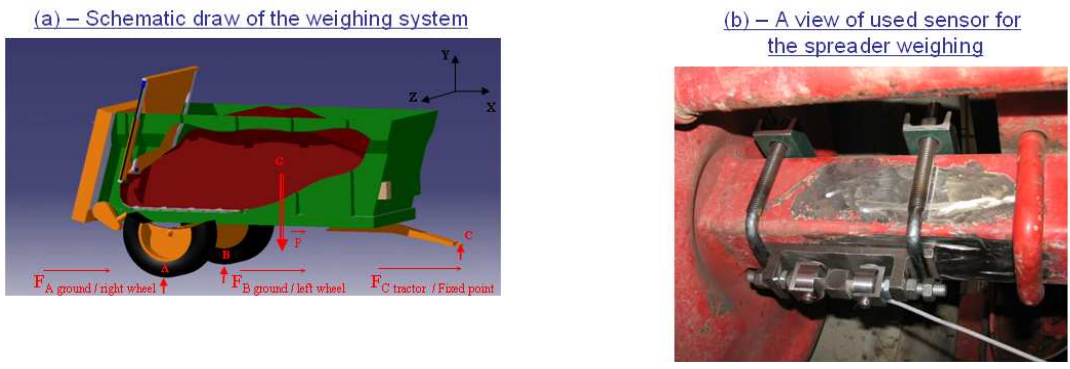


Fig 5: Description of the weighing measure installed on the manure spreader.
 (a) Schematic draw of the weighing system
 (b) A view of used sensor for the spreader weighing

2.2.4 Data analysis

The basis for the analysis of all sets of experiments was the European Standard EN13080. For this, load cells are placed under the spreader and the tractor to weight continuously the total mass of the tractor, the spreader and the product during the hopper unloading. This measurement is achieved in static at a frequency of 2 Hz. Then, the mass flow is calculated, and filtered with a low pass (Fig 6.a).

The Figure 6.b represents a curve commonly obtained with a manure spreader according to the standard EN13080. Several parameters can be calculated from this flow rate curve. The first parameter is the characteristic flow rate. It corresponds to the highest average flow rate occurring during 30% of the unloading time of the spreader. From this characteristic flow rate is defined a tolerance zone which is between $\pm 15\%$ of the characteristic flow rate. The percentage of the unloading time during which the flow rate is in the tolerance zone is calculated and defined as the stretch within the tolerance zone. The longitudinal coefficient of variation is calculated on the average flow. It translates the flow rate variability during the spreader unloading.

To satisfy the EN13080 standard, the longitudinal CV must be lower than 40% and the stretch within the tolerance zone must be higher than 35%.

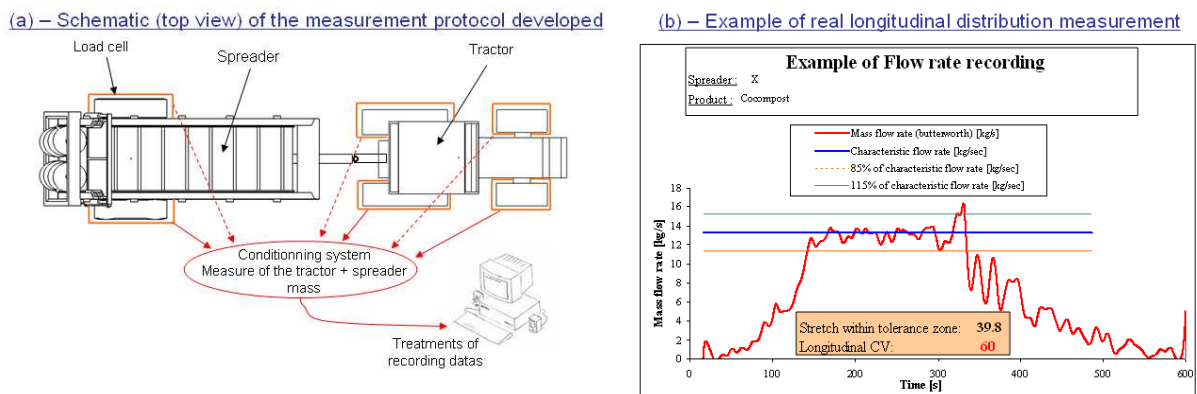


Fig 6: Description of the weight measurement device installed on the manure spreader.
 (a) Schematic draw of the measurement protocol
 (b) Example of longitudinal distribution curve

3 Results

Three different products were used to evaluate the flow rate control of the spreader: a feedlot manure with straw, a compost of feedlot manure and a co-compost of green wastes mixed with fermentable domestic wastes. For each product, two measurements of the flow rate were done according to EN13080 Standard. The first plot at the left in Fig. 7.a, Fig 8.a and Fig 9.a shows the longitudinal flow rate result obtained with the spreader without flow rate control. In the other side, the plot in Fig. 7.b, Fig 8.b and Fig 9.b shows the longitudinal flow rate result obtained with the spreader with the developed flow rate control.

All the presented plots were obtained with the first stage of the flow rate control. The control of the mass flow during the hopper unloading was performed by enslaving the scraper conveyor speed to the height of the product on beaters with knowledge of the height of the flow-control gate. The continuous measurement of the flow rate was not installed for these tests. The product is considered constant for each spreader unloading. Since a mass measurement was done just after each spreader loading, the calculation of the product volumetric mass is easy, taking into account the spreader volume.

3.1 Longitudinal flow rate records

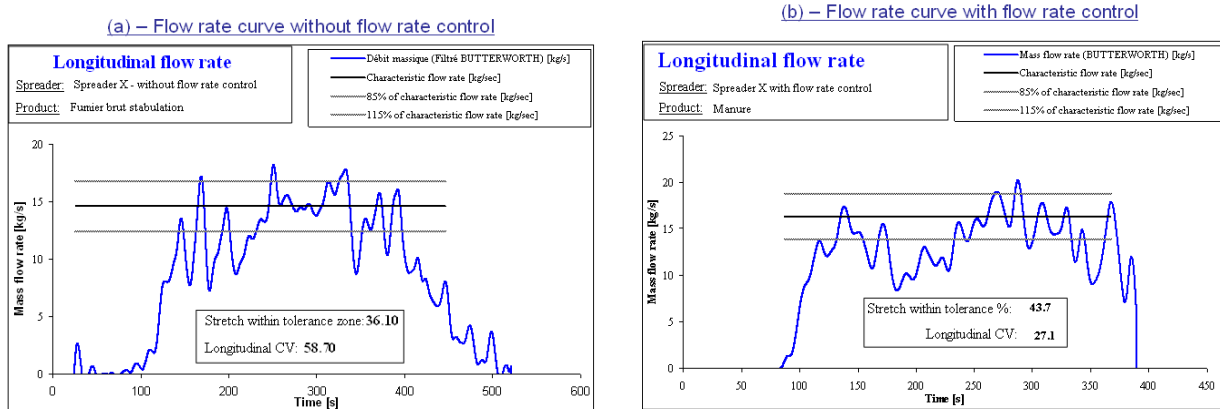


Fig 7: Measure of longitudinal flow rate according to standard EN13080 for manure
(a) without flow rate control
(b) with the flow rate control

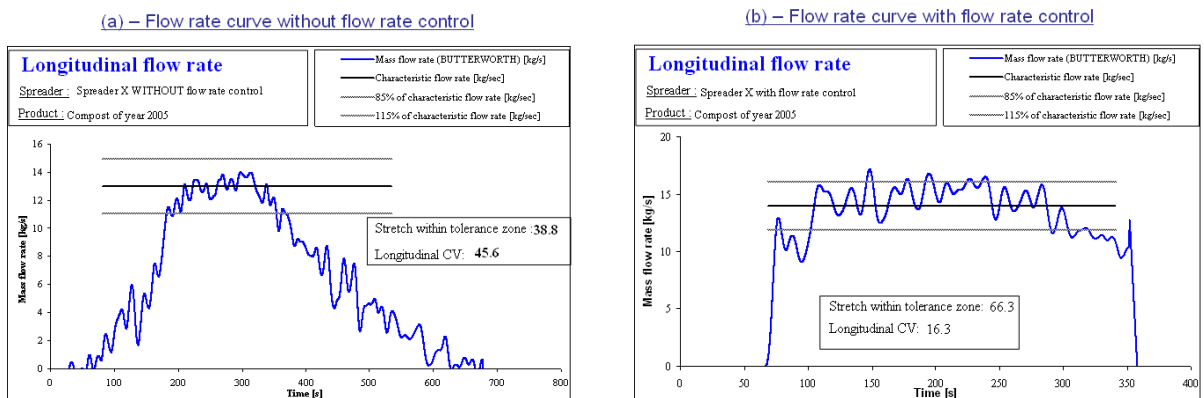
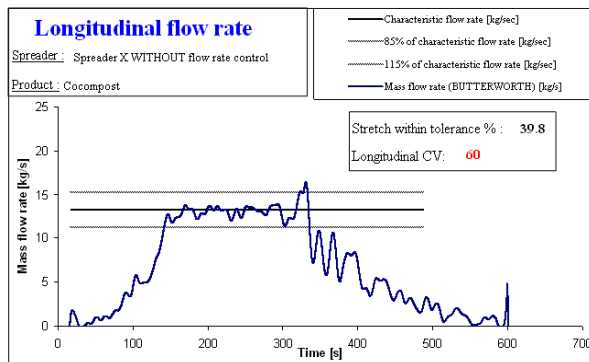


Fig 8: Measure of longitudinal flow rate according to standard EN13080 for compost product
(a) without flow rate control
(b) with the flow rate control

(a) – Flow rate curve without flow rate control



(b) – Flow rate curve with flow rate control

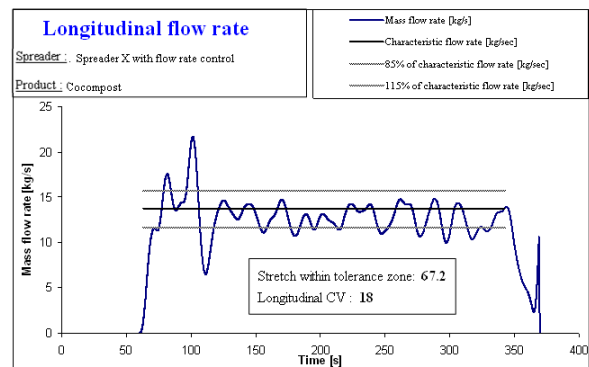


Fig 9: Measure of longitudinal flow rate according to standard EN13080 for co-compost product
 (a) without flow rate control
 (b) with the flow rate control

For the three measures without scraper conveyor control, there is always a little time range with a constant flow rate. This is the area where there is no product crumbling. The rest of the time corresponds to areas where the flow rate increases (at the beginning of the spreader unloading) or where the flow rate decreases (at the end of the spreader unloading).

For the three measurements with the scraper conveyor speed control, the longitudinal flow rate curves present a rectangular shape as expected. The areas which show problems without electronic are removed. It only remains variability on the results; this noise is higher for the manure than for the compost or the co-compost. Indeed, composted products are homogenized, with more regular particle shapes, and are less ejected by the beaters in package, at the opposite of manure with straw which presents a great variability.

The noise is more important for results with electronic because the distance between the gate and the beaters is very important on our experimental spreader (0.8 meter). Traditionally, the gate prevents crumbling in the hopper before the gate. In our case, due to experimental specific spreader geometry, there isn't any device to avoid product crumbling in the interval between the gate and the beaters. This phenomena is particularly visible for the composted product.

3.2 Results synthesis

Table 1: results synthesis of longitudinal flow rate measurement according the EN13080 Standard for 6 tests with three products (comparison between a normal spreader and the same spreader equipped with a flow rate control):

	Manure		Compost of manure		Co-compost	
	Without flow rate control	With flow rate control	Without flow rate control	With flow rate control	Without flow rate control	With flow rate control
Stretch within tolerance zone (The standard is satisfy if > 35%)	36.1	43.7	38.8	66.3	39.8	67.2
Longitudinal CV (%) (The standard is satisfy if < 40%)	58.7	27.1	45.6	27.5	60	18
Unloading time (s)	329.4	211.9	308.2	208.5	332.9	215.6
volumetric mass (kg/m³)	690	738	663	620	648	675

The table 1 summarizes all the calculated data according to the protocol of the EN 13080 standard for longitudinal point of view. That is, in particular the stretch within the tolerance zone, the longitudinal CV, the total unloading time and the density of three products used for the six longitudinal distributions.

In terms of standard respect, for trials without scraper conveyor speed activation, the stretch within the tolerance zone is very difficult to reach. For the longitudinal CV, it is the same, results don't satisfy the standard. All the Longitudinal CVs are higher than 40% and all the stretch within the tolerance zone are limit.

For measurements with scraper conveyor under control in regard with the gate height, the performance levels are significantly improved. The results of stretch within the tolerance zone and the longitudinal CV fully satisfy the EN13080 standard. The percentage of time spent in the tolerance zone is almost doubled compared to tests without control for the composted products. Indeed, the period of flow rate decreasing which appears in the second part of the spreader unloading is corrected by increasing the scraper conveyor speed. The volumetric discharge is also almost constant.

The worst result (but satisfying the standard) is for the manure. In this case, the product heterogeneity induces a lot of flow rate variation (which penalizes the standard criteria). Despite the product variability, the longitudinal CV is less important than 40% thanks to the speed correction of the scraper conveyor.

Thanks to the presented control, the longitudinal CV is divided by 2 or 3 depending on the types of products.

For the three products, the unloading time is reduced by one third using the proposed control over the tests without control. This phenomenon is due to the variable speed of progress of the scraper conveyor. Indeed, the flow rate decreasing encountered during the second part of the spreader conveyor is compensated and thus reduced by this principle.

4 Conclusion

This study showed gains thanks to the developed control which consists in automatically compensate the scraper conveyor in regard with the product section which feeds the beaters. Some real measurements of longitudinal distribution curves show improvements to expect from an application using the proposed control. Three very different products were tested alternately with and without control of the scraper conveyor. The automatic manure profile tracking was done by sensor adding on the gate. The tests were performed according to EN 13080 standard, which calculates two criteria in order to characterize the longitudinal distribution: the stretch within the tolerance zone and the longitudinal CV. Results are significantly improved by the process control. For our spreader, the percentage of time spent in the zone of tolerance is multiplied by two and the longitudinal CV is divided by three. Long period of regular decreasing flow are fully avoid using the proposed regulation. These curves are much more rectangular for each fertiliser tested.

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