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Pendulum-action spreader for lime application

Distribuidor pendular para aplicação de calcário

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ABSTRACT
Currently the centrifugal spreaders are the most used for lime application in Brazil. The pendulum-action spreaders have characteristics that differentiate them from the centrifugal, such as a symmetrical pattern and the possibility to apply in different widths with the spout change, but are normally not used for lime application due to its high rates. The objective of this work was to resize, create and evaluate a pendulum-action spreader able to distribute lime, at flows larger than 1.50 kg s^{-1}, usually found in conventional models. A prototype with volumetric measure mechanism and eletric motor drive, connected to a frequency inverter, was developed. Polyvinyl chloride (PVC) pendulums with different lengths were used, with and without a ramp at their ends. Experiment tests were conducted in a completely randomized design with three replications using 7 x 3 x 2 factorial arrangement consisted of seven frequencies, three spout lengths and the use of a ramp at its end. Regarding bandwidth, the ramp utilization in the lowest frequency (1.73 Hz) did not increase the

launch distance for 0.2 and 0.3 m spouts lengths. The distance values ranged from 1.89 to 5.69 m. The maximum value was obtained with the longest spout length (0.30 m), highest frequency (5.20 Hz) using the ramp, and the minimum value, with the smallest spout (0.10 m), lowest frequency (1.73 Hz) without the ramp. In general, the increment of spout length and operating frequency, besides the ramp use, increased lime bandwidth application with the proposed pendulum-action spreader, indicating its potential to compose a different solution for high lime rates applications. Furthermore, it has been shown that is possible to vary the width of the application range by modifying the length of the tube, frequency and the use of the ramp.

Keywords: band distribution, bandwidth, frequency, ramp, spout length

RESUMO

Atualmente, os espalhadores centrífugos são os mais utilizados para aplicação de cal no Brasil. Os espalhadores de pêndulo-ação possuem características que os diferenciam do centrífugo, como um padrão simétrico e a possibilidade de aplicação em diferentes larguras com a troca de bico, mas normalmente não são utilizados para aplicação de cal devido às suas altas taxas. O objetivo deste trabalho foi redimensionar, criar e avaliar um espalhador de pêndulo-ação capaz de distribuir cal, em vazões maiores que 1,50 kg s^{-1}, geralmente encontradas em modelos convencionais. Foi desenvolvido um protótipo com mecanismo de medida volumétrica e acionamento do motor elétrico, conectado a um inversor de frequência. Foram utilizados pêndulos de cloreto de polivinila (PVC) de diferentes comprimentos, com e sem rampa nas extremidades. Testes experimentais foram conduzidos em um delineamento inteiramente casualizado, com três repetições, utilizando arranjo fatorial 7 x 3 x 2, composto por sete frequências, três comprimentos de bico e o uso de uma rampa no final. Em relação à largura de banda, a utilização da rampa na frequência mais baixa (1,73 Hz) não aumentou a distância de lançamento nos comprimentos de bicos de 0,2 e 0,3 m. Os valores da distância variaram de 1,89 a 5,69 m. O valor máximo foi obtido com o maior comprimento do bico (0,30 m), a maior frequência (5,20 Hz) na rampa e o valor mínimo com o menor bico (0,10 m), a menor frequência (1,73 Hz) sem a rampa. Em geral, o incremento no comprimento do bico e na frequência de operação, além do uso da rampa, aumentou a aplicação da largura de banda do cal com o espalhador de ação pendular proposto, indicando seu potencial para compor uma solução diferente para aplicações de altas taxas de cal. Além disso, foi demonstrado que é possível variar a largura da faixa de aplicação, modificando o comprimento do tubo, a frequência e o uso da rampa.

Palavras-chave: distribuição de banda, largura de banda, frequência, rampa, comprimento do bico

1 INTRODUCTION

Brazilian agricultural soils are limited by the common presence of medium and high acidity levels (Raboin et al., 2016; Tiritan et al., 2016) that reduces crop yield potential (Nóia et al., 2014; Da Costa & Crusciol, 2016) and negatively impact the economic balance (Teixeira et al., 2015).

Soil acidity neutralization rely on the application of basic compounds to the soil (Alcarde, 1986). The application of powdered lime, also known as liming, is a common (Ramos, 2006; Bonfim-Silva et al., 2019), efficient (Li et al., 2019) and low cost way (Souza et al., 2011) to increase the soil pH.

In Brazil, there is a high consumption of around 30 million tons per year of lime, but it does not reflect on a high quality liming application (ABRACAL, 2019). The low quality of liming application is consequence of the scarcity of dedicated equipment (ABRACAL, 2019), highlighting the needs to make efforts in research and development of alternative solutions.

The most used equipment for liming and fertilizer applications are built-in centrifugal spreaders (Laghari et al., 2014). These models are usually associated with large load capacity providing larger autonomy working width (Laghari et al., 2014; Luz, 2002). The distribution mechanism of centrifugal spreaders relies on discs that makes a radial distribution of the material on the ground. This system configuration causes an uneven material distribution over an area making necessary constant evaluation and calibration of the system (Cunha & Filho, 2016).

There is also the pendulum-action spreaders, which are the focus of this study. They are associate with mounted, low capacity distributors, for granular fertilizer. As it carries a gravity flow mechanism it does not work for powder material like lime, especially for the usual high rates of local farms. Despite the evolution stagnation of pendulum-action spreaders, these models present two notable technical features that differentiate them, especially from the centrifugal spreaders, as they produce a symmetric spreading pattern and can spread in bands (Parish, 1995).

Regarding pendulum-action spreaders performance, manufacturers indicate that change in spout length directly influences swath widths (Vicon, 2018; LandPride, 2018). Mursec & Ploj (2002) studied the influence of power takeoff (PTO) rotation on fertilizer wide range and concluded that larger widths were achieved with higher PTO rotations. Bahaosean & Brouns (1998) increased the distribution width adding a ramp at the end of the spreading spout, which add a vertical component to the velocity vector of the particles being ejected.

In this context, the aim of this work was to resize and evaluate a pendulum-action mechanism dedicated to fertilizers, for banding applications at higher rates of lime than the current and to evaluate the influence of operating frequency, spout length and ramp utilization.

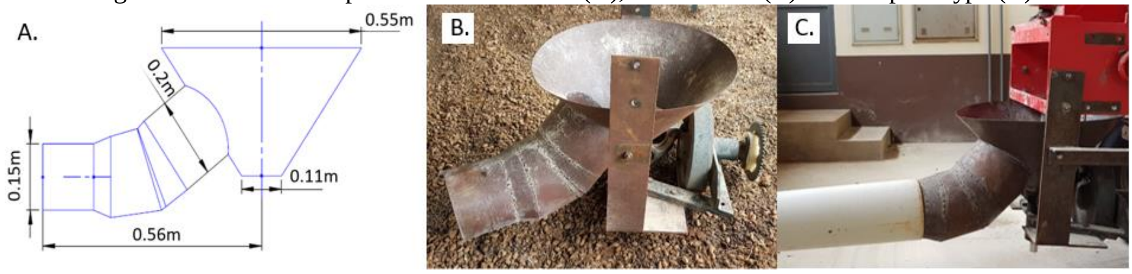
2 MATERIAL AND METHODS

A ballistics study to predict the launch distance of lime particles was not carried out in this study because it has been already reported that there are differences between empirical and theoretical launch values (Olielagers et al., 1996; Aphale et al., 2003; Dintwa et al., 2004). Therefore, the study was conducted applying the empirical method based on Silva (1991) as a reference for decision-making.

A prototype was built based on two distributors: a centrifugal spreader with a volumetric meter mechanism composed of a conveyor belts and flow port (DCA5500, Tatu Marchesan, Matão, Brazil) and a pendulum-type spreader (P600, Vicon, Cotia, Brazil). The first had its distributor mechanism removed and replaced with the pendulum-action mechanism, resized and built using the moving components (flywheel, structure, yoke assembly and bearings) from the commercially available pendulum spreader.

A funnel was designed (Figure 1A) and built (Figure 1B) with its nozzle output set parallel to the ground to guide the particles movement. A ball bearing base was welded under the funnel to allow horizontal movement. It was fixed a polyvinyl chloride (PVC) tubes with 0.15 m diameter to the nozzle output. To construct the ramp, PVC tubes were laid parallel to the soil and it was added a PVC ramp at the end of the tube with 30º, covering entirely the underside (Figure 1C).

Figure 1. Funnel development. Funnel sketch (A), built funnel (B) and the prototype (C)



Different from the current models, which are moved through a cardan shaft connected to the tractor´s power take-off, the movement of the set was carried out through a three-phase electrical motor (4-pole, 2kW) (WEG, Jaraguá do Sul, Brazil), cogwheels (motor, 16 teeth and driven, 48 teeth) and chain. As the frequency was also a factor, a Pulse-Width Modulation (PWM) frequency inverter (Siemens, Jundiai, Brazil) was used to control the rotation of the electrical motor. In addition, its use allowed a gradual acceleration and the elimination of several reductions to achieve the desired rotation.

A range of rotations on the steering wheel from 52 to 156 rpm was used. The lower limit was determined by the frequency of operation that material flow began to occur inside the pendulum. The upper value was determined by the mechanical strength of the structure. Furthermore, five other values were defined within this range. It is noteworthy that each rotation of the steering wheel represents two movements on the pendulum.

The rotations on the steering wheel were measured with a DT-2244B photo tachometer (Minipa, São Paulo, Brazil), allowing to define the ratio between the frequency in the inverter and the equivalent pendulum frequency.

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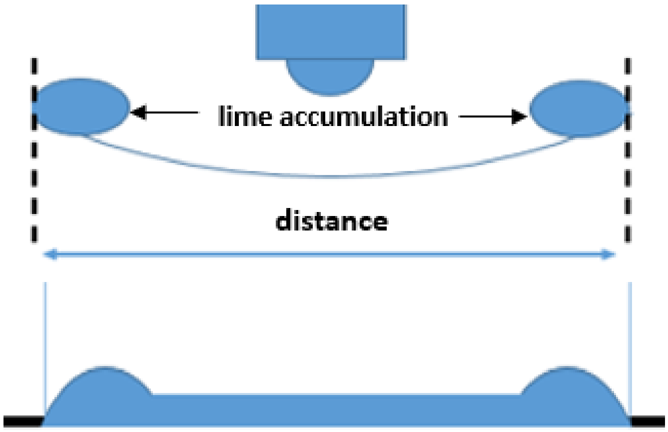
The performance evaluation was conducted with commercial limestone (Diamante, Tiete, Brazil) at the Precision Agriculture Laboratory of the "Luiz de Queiroz College of Agriculture", University of São Paulo (Piracicaba, SP, Brazil). The physical characteristics of the limestone is described in Table 1.

Table 1- Lime physical characteristics

Mesh	Retained in sieve (%)
10 (2.00 mm)	0.00
20 (0.84 mm)	7.00
50 (0.30 mm)	32.00
Density (g cm^{-3})	1.39
Humidity (%)	0.62
Rest angle (°)	33.70

Due to the large number of tests and repetitions, it was necessary to use a methodology that would allow the tests to be carried out in an agile and efficient manner. Therefore, the tests were performed on a static mode, on a flat surface, at 0.35 m above the ground and on a black canvas. The bandwidth, horizontal distance between the extreme material heaps, was measured with a measuring tape (**Erro! Fonte de referência não encontrada.**).

Figure 2. Sketch of the bandwidth measurement



During the tests, the material volume level within the funnel was fulfilled constantly to provide enough material deposition in different frequencies. The maximum flow rate was calculated with the distributor mechanism at its maximum frequency (5.20 Hz) and the mass of the material distributed over a period of 60 seconds was measured. Three repetitions were performed for each condition.

The statistical design used was completely randomized composed of a triple factorial 7 x 3 x 2 with three replications, totalizing 126 tests. The three factors were frequency (1.73, 2.60, 3.47, 3.90, 4.33, 4.77 and 5.20 Hz), length of PVC tubes (0.10, 0.20 and 0.30 m), and ramp (with and without its use). Analysis of variance (ANOVA) followed by a multiple mean comparison test of Tukey at 5% probability was performed on the R environment (R Core Team, 2018)

3 RESULTS AND DISCUSSION

A maximum flow rate of 6.5 kg s^{-1} was found at the highest pendulum frequency (5.2 Hz). The flow rate of 6.5 kg s^{-1} reached by the proposed prototype is higher than those found in conventional pendulum-action spreaders (1.5 kg s^{-1}). This result was obtained due to the volumetric mechanism meter and the larger pendulum diameter (0.15 m), instead of the 0.06 m usually found in conventional models.

Frequency inverter proved to be suitable for rotation control, changing operational frequency without switching the cogwheels ratio that allows to use for variable rate applications on real time. Table 2 shows the equivalence between the frequency of the inverter and pendulum movements. An increment of 1 Hz in the frequency affords an additional 0.43 Hz in the pendulum frequency.

Table 2: Frequency of the inverter and its equivalence in the spout.

Inverter frequency (Hz)	Spout frequency (Hz)
4.00	1.73
6.00	2.60
8.00	3.47
9.00	3.90
10.00	4.33
11.00	4.77
12.00	5.20

It was challenging to reach the common frequencies used in pendulum distributors with the proposed prototype due to the greater mass of the system (funnel/pendulum set). Therefore, the maximum frequency used in the tests, 5.2 Hz, was lower to those found on conventional pendulum spreaders, which have a direct ratio (1:1) and work at about 18 Hz.

The drawback in pendulum-action principle is the high acceleration and deceleration that occurs several times per second, unlike centrifugal distributors, that accelerate the discs only at the beginning of their operation, maintaining a constant movement. According to Bahasoean & Brouns

(1988), the change in kinematics (higher frequency or larger oscillation angle) results in a quadratic increase of the force acting on the spout. In this way, mechanical strength becomes a limiting factor.

It was observed, even in lower frequencies, that some launch values were close to the conventional ones. Fact that shows the difficulty in launching small-mass particles. Therefore, after a certain moment, the increase in energy will not result in larger distances.

Figure 3 presents the results for the 0.10 m spout length at different frequencies, with and without ramp use and Tukey´s test classification, which indicated no significant difference between the bandwidth obtained between the frequencies 4.33 and 4.77 Hz for both configurations, as well as for the ramp use at 2.60 Hz. Except for those frequencies, it was noted that for the 0.10 m spout, the increase in frequency and the ramp use resulted in larger launch distances due to the increase of kinetic energy and also the addition of a vertical velocity component, creating a parabolic trajectory.

Figure 3. Comparison between the bandwidth (m) obtained for 0.10 m spout at a 5% probability with Tukey's test. Lower case letters compare spouts of different configurations at the same frequency; capital letters compare spouts without ramp at different frequencies; bold and italic letters compare spouts with ramp at different frequencies.

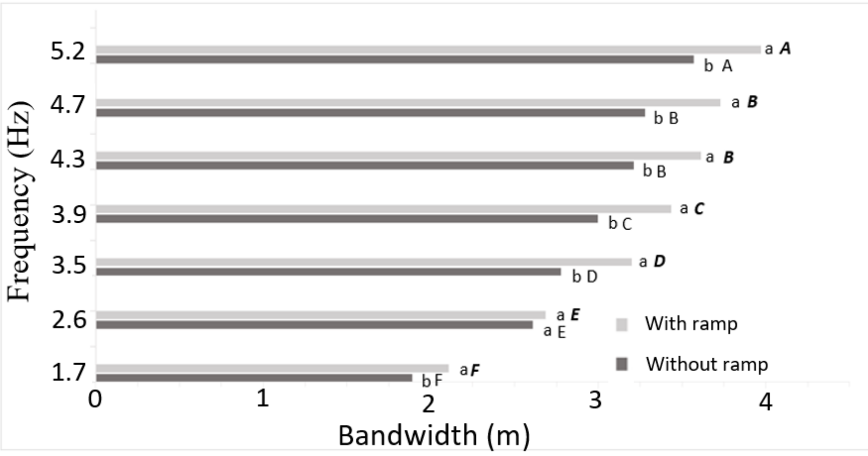


Figure 4 and Figure 5 present the results for 0.20 and 0.30 m spouts length. In general, the frequency increase and the use of the ramp allowed the particles to be launched at larger widths. However, at 1.73 Hz, the addition of the ramp resulted an opposite response to the expected one, reducing the bandwidth. At this frequency, due to the low particle exit velocity, the ramp became an obstacle that reduced the exit velocity and, consequently, the launching distance. The better performance of the 0.10 m spout in this situation is due because it was closer to the exit nozzle, providing the particles a higher speed at the end of the ramp produced by the acceleration during the travel through the funnel, built with a slope. The results obtained by Tukey´s test at 5% probability indicated that there was no significant difference between the distances obtained by the

0.20 m spout without ramp at 3.47 and 3.90 Hz, as well as for the use of ramp at 3.47 Hz for 0.20 m and 0.30 m spout.

Figure 4. Comparison between the distances obtained for 0.20 m spout at a 5% probability with Tukey's test. Lower case letters compare spouts of different configurations at the same frequency; capital letters compare spouts without ramp at different frequencies; bold and italic letters compare spouts with ramp at different frequencies.

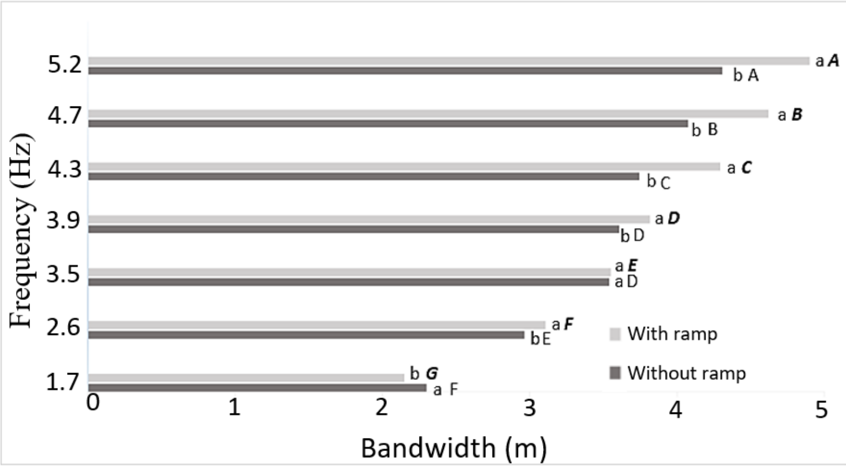
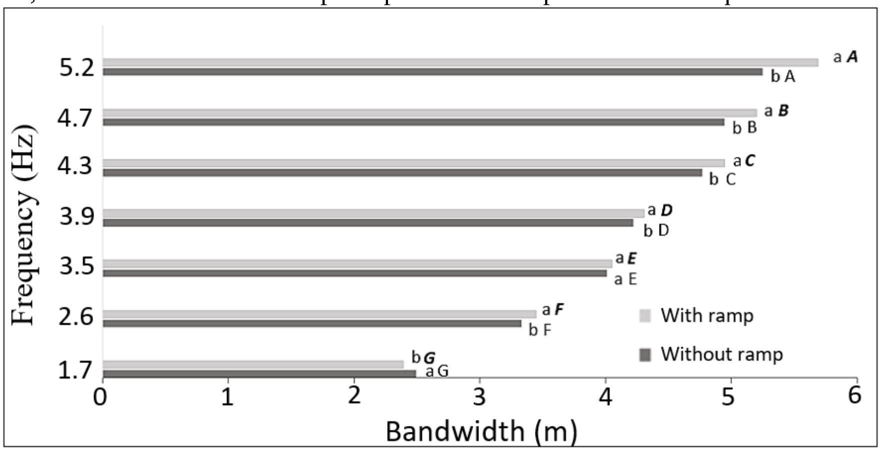


Figure 5. Comparison between the distances obtained for 0.3 m spout at a 5% probability with Tukey's test. Lower case letters compare spouts of different configurations at the same frequency; capital letters compare spouts without ramp at different frequencies; bold and italic letters compare spouts with ramp at different frequencies.



In general, the increment in spout length and operating frequency, besides the ramp use, increased the bandwidth. It is emphasized that these results can be influenced by many factors, such as size, shape, density and humidity of the particle, air resistance, friction coefficient (between tube and particle) and wind (Reumers et. al, 2003).

The results from this study were similar to those observed in the literature. Mursec & Ploj (2002) reported a decrease in fertilizer particles launch, and consequently the spread width, by reducing the PTO rotation for both mono-disk rotary spreader and pendulum-action spreader. Parish

& Bergeron (1991) described that the variation in PTO rotation and spout length have the capacity to deliver relatively discrete bandwidths. Although the material is different, the same behavior was expected. It is known that the amount of kinetic energy of a particle is directly proportional to its mass (kinetic energy is equal mass multiplied by velocity squared, divided by two). Considering that an average limestone particle is about 0.8 mm in diameter, density of 1.39 g cm^{-3} and weight of each particle is about 1 x 10^{-5} grams (0.01 mg), it is reasonable that powder lime particles reach shorter distances than those found for fertilizers particles.

It was possible to distribute powdered lime using the pendulum-action principle by building a prototype. The main differences of this principle were shown to be symmetry and band application in the absence of the deflector. The modification of the spout length and frequency proved to be effective in varying the launch distance. The drive of the system through an electric motor proved to be an alternative to the cardan shaft (connected to the tractor's power take off), with the advantage of simply and quickly changing the rotation through a frequency inverter. From the collected data, the ANOVA results indicated a significant difference among all factors and their interactions at 5% significance level. This indicates that length, frequency and ramp utilization influence the bandwidth.

Regarding to the distribution pattern, it was found a material accumulation at the edges. This type of pattern is suitable and desirable for band application in perennial crops such as coffee (Salamanca-Jimenez et al., 2017) or to chemical nutrients that are considered immobile in soil such as P (Chien et al., 2009).

4 FUTURE PERSPECTIVES

The work provided new study possibilities, which would be of great value to complete the review, and thereby increase data availability on pendulum-action spreaders. Important topics include the development and analysis of a deflector that could make the material deposition more homogeneous, allowing total area application and increasing the pendulum-action spreader´s potential application. System weight reduction, especially excluding the funnel, would enable tests at higher frequencies and, consequently, higher flow rates. A prototype with higher mechanical resistance should be used to test longer spout lengths and analyze their influence on material deposition. Another feature to be evaluated is the influence of different ramp angles and powder materials.

5 CONCLUSIONS

The built prototype was able to spread at a flow rate of 6.5 kg s^{-1} of powder lime at 5.2 Hz, value much higher than those found for conventional pendulum-action spreaders, of about 1.5 kg s^{-1} for the same material.

The use of an electric motor and a frequency inverter proved to be an effective way to control de rotation (speed) of the set, and an alternative to the cardan shaft.

The study also indicated that the launch distance is influenced by the spout length, operating frequency and whether or not a ramp is added at the end of the pendulum. Through the modification of these variables, the prototype was able to carry out distributions in different widths, with values ranging from 1.89 to 5.69 m. The smallest and largest width of the range were obtained, respectively, using the 0.10 m spout length at 1.73 Hz without ramp and 0.30 m spout length at 5.20 Hz with ramp. Longer spout lengths have to be tested.

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