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Static and kinematic tests for determining spreaders effective width

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Abstract. *Spinner box spreaders are intensively used in Brazil for variable rate applications of lime in agriculture. The control of that operation is a challenging issue because of the complexity involved on the interactions between product and machine. Quantification of transverse distribution of solids thrown from the spinner box spreaders involves dynamic conditions tests where the material deposited on trays is evaluated along the pass of the machinery. There is a need of alternative testing methods capable to make the spreader evaluations more efficient. The objective of this study was to compare three methods for the determination of effective width for limestone application. A double disc spinner box spreader pulled by the PTO tractor was used. The flow rate was set at 3.0 kg s^{-1} and three replicates of kinematic, static grid, and radial static scenarios were evaluated. The speed in kinematic test was set at 1.21 m s^{-1}. During the static evaluations the spreader stayed in operation for 30 s with a PTO speed of 540 rpm. The radial test was done with nine rows of trays separated by an angle of 20º, starting joined in one side, and then finishing separated by 0.25 m on the other side. For all scenarios plastic trays of dimensions 1.00 x 0.25 x 0.15 m were used to collect the material of the samples. To get the weight of the samples a balance with 0.01 g sensibility and a capacity of 5,000 g was used. Static grid and kinematic tests were analyzed based on the coefficient of variation at 20% using the software Adulanço, while the data of the radial test was interpolated using QGIS in a grid of 0.5 m x 0.5 m. Regarding the results between kinematic and static grid tests, the highest mean relative error of effective width was 21.6%. Using Tukey test at 5% level some statistical differences were observed depending on the trajectory. Data had high CV variation (ranged between 78.51% and 115.51%) among replicate treatments, so that further studies are needed to understand those variability aspects.*

Keywords.
distribution test, limestone, spinner box width.

INTRODUCTION

Brazilian agriculture represents the 6% of the total global consumption of fertilizer, being the fourth largest consumer in the world. Those inputs are used in major crops such as soybean, corn, sugarcane and coffee (FAO, 2009). According to the National Department of Mineral Production (DNPM), limestone production in Brazil reached an estimate of 107 million tons in 2015, where about the 21% is used for agriculture production (DNPM, 2015).

Variable rate application systems, especially for soil, can be used in order to improve the rationalization of inputs, as well as the yield response of the crop. Molin et al. 2010 verified on coffee (*Coffea arabica* L.) that areas covered with variable rate applications of phosphorus and potassium showed an increase in yield of 34%, when compared with areas of fixed rate applications.

When the material is applied at variable rates, the user have to be sure that the machine is capable of maintain the distribution pattern independently of the flow rate, for what alternative ways for testing can help to accelerate the procedure and reduce the use of materials (ANTILLE et al., 2015; VIRK et al., 2013).

To determine the quality of transverse distribution of solid fertilizers thrown by spinner box spreaders, some dynamic conditions are involved in the path of the particles going from the distribution point, up to the trays where the material is deposited along the pass of the machine (COOL et al., 2014).

The quality of the distribution in spinner box spreaders applications is affected by the physical characteristics of products, which can cause abnormalities in the distribution of the material. Baio et al. (2012) evaluated the transversal distribution of solid fertilizers applied over annual crops, and determined that crop phenology (cotton and maize) directly affected the effective width of the spinner box spreader, result which was not repeated for soybean.

ASAE standards (2003), and ISO 5690 (ISO, 1985) represent the guidelines for the analysis of distribution patterns by cross fertilizing based on the coefficient of variation (CV) obtained in tests. The objective of this study was to compare three methods for the determination of the effective width of limestone using a double disc spinner box spreader.

MATERIAL AND METHODS

Plastic trays of dimensions 1.00 m x 0.25 m x 0.15 m, were used according to the ISO 5690 (ISO, 1985) and ASAE standards (2003). A PTO driven spinner box spreader (model: DCA-2MC-5500, Tatu Marchesan, Matão, SP), pulled by a tractor (63 kW) was used in this study.

The flow meter, in charge for the opening of vertical sliding door and speed of belt, was set at 3.0 kg s^{-1}. The double disk mechanism (4 spreaders disks) operates under the centrifugal mechanism for material distribution. During the kinematic tests, speed was set at 1.21 m s^{-1}, whereas during the statics tests the machine was maintained in operation in time lapses of 30 s, with a PTO speed of 540 rpm. The theoretical dosage (T) of material was calculated according to the equation 1.

$$T = \frac{Q}{L \times v} \times 10000 \quad (1)$$

where, T = dosage (kg ha^{-1}); Q = flow rate (kg s^{-1}); L = effective width (m); v = driving speed (m s^{-1}).

Three scenarios were evaluated: kinematic, static grid and radial static, with three replications in

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each one. For kinematic scenario (Figure 1), trays were arranged in three parallel rows at 3.0 m between them, and each row having 29 trays with a spacing of 0.25 m. In the sides of the center line (15th tray), tray spacing was 0.75 m in order to leave a free space for the pass of the tractor at 1.21 m s^{-1}. For that case the machinery ran three times through the center line of the area, characterizing so the three replications.

Fig. 1 - Arranged trays (left) for kinematic scenario (right)

Static grid scenario (Figure 2) was arranged using 29 rows and 8 columns. The three central rows contained seven trays due to the necessary space for tractor. Distance between rows and trays of the same row were set at 0.25 m. Samples from material distributed by the spreaders were collected from each row of trays as one replication.

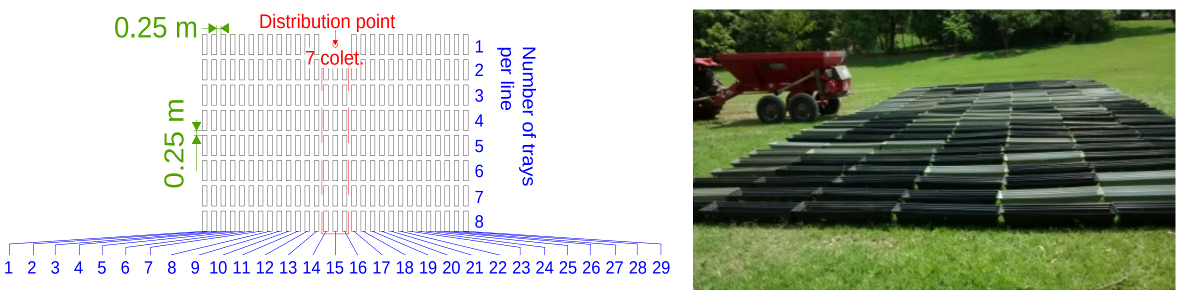

Fig. 2 - Arranged trays (left) for static grid scenario (right)

Radial static scenario (Figure 3) was developed according to the methodology proposed by Cool et al. (2015). A total of 114 trays, spaced at 0.25 m, were arranged in eleven rows (A to K), and were separated by an angle of 3º from the horizontal axis in the extreme rows, and by 17 º between all the other internal rows.

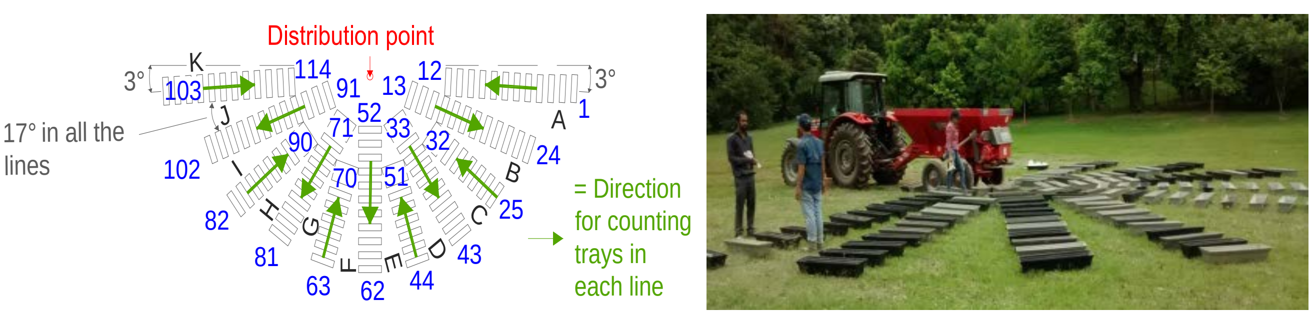

Fig. 3 - Arranged trays (left) for static radial scenario (right)

A comparison between the tree scenarios was performed following the methodology proposed by Cool et al. (2015). The parameters evaluated were: relative error, average dosage and coefficient of variation. The relative error (Re) was calculated between replications and scenarios according to the equation 2.

$$Re = \frac{\sum i \sum j \left| M_{ij} - N_{ij} \right|}{\sum i \sum j M_{ij} + \sum i \sum j N_{ij}} \times 100 \quad (2)$$

where Re = relative error (%), $M_{i,j}$ and $N_{i,j}$ = mass at grid cell at longitudinal position i and transverse position j (g).

The dosage of fertilizer at transverse position (T_j) was calculated according to the equation 3.

$$T_j = \frac{72 \sum i M_{ij}}{v \times t} \quad (3)$$

where T_i = dosage of fertilizer at transverse position j (kg ha^{-1}), $M_{i,j}$ = mass at grid cell at longitudinal position i and transverse position j (g), v = driving speed (km h^{-1}) and t = sampling time (s).

The coefficient of variation was calculated using the equation 4.

$$CV = \frac{\sqrt{\sum j \left(T_j - \overline{T}\right)^2}}{\sqrt{n-1} \times \overline{T}} \times 100 \quad (4)$$

where CV = coefficient of variation (%), T_i = dosage of fertilizer at transverse position j (kg ha^{-1}), $\overline{T}$ = average transverse dosage (kg ha^{-1}) and n = number of transverse positions.

All samples were weighed in a balance with a sensibility of 0.01 g and capacity of 5,000 g. Static grid and kinematic scenarios were analyzed based on the coefficient of variation, at 20%, using the software ADULANÇO version 3.1 (MOLIN et al., 1992) and data from radial test were interpolated using a Geographic Information System (SIG) software named as QGIS version 2.14 in a grid of 0.5 x 0.5 m.

RESULTS AND DISCUSSION

Relative error between three scenarios is shown in Table 1. The highest mean relative error (21.6%) of effective width was observed between the kinematic and static grid tests. While the lowest error (3.27 %) was observed between kinematic and radial static scenarios. The additional data plots are presented in Appendix-A.

Table 1 - Relative error between scenarios (all in %)

Scenarios	R1	R2	R3	Mean
Kinematic x Static grid	46.35	46.24	39.59	21.61
Kinematic x Radial static	5.61	14.21	7.10	3.27
Radial static x Static grid	50.64	56.72	45.42	18.47

R1: repetition 1; R2: repetition 2; R3: repetition 3

Table 2 shows the average dosage, expressed as a percentage in relation to the theoretical dosage, as well as the CV of each repetition and scenario. Results suggest that radial static scenario overestimated the application rate of material, while other scenarios underestimated this value.

Table 2. Average dosage ($\overline{T}$), expressed as a percentage in relation to the theoretical dosage, and CV for repetitions and scenarios (all in %)

Scenarios	$\overline{T}_1$	CV_1	$\overline{T}_2$	CV_2	$\overline{T}_3$	CV_3
Radial static	104.67	108.73	134.16	101.88	91.26	97.90
Static grid	81.05	90.53	74.58	82.08	93.83	78.51
Kinematic	82.92	112.20	75.90	115.51	65.89	109.60

$\overline{T}$: average dosage (%); CV: coefficient of variation (%)

Cool et al. (2015) reported lower variation between fertilizer application replications (CAN, NPK and KCl) compared with the results obtained here, so that further studies are needed to understand such variability. The comparison of effective width distribution among studied scenarios is presented in

Table 3. No statistical difference was determined in the effective width of the path system (alternating right, alternating left and continuous (MOLIN and MENEGATTI, 2003)) in the static scenario, but there is a difference for kinematic test which had lower effective width (4.16 m) in continuous distribution system. The higher effective width, 8.33 m, was observed for static grid.

Table 3 - Comparing the effective width distribution among scenarios evaluated

Distribution System[1]	Radial static	Static grid	Kinematic
	effective width (m)		
Alternating right	5.83 aB	8.25 aA	4.75 aB
Alternating left	5.75 aB	8.25 aA	4.91 aB
Continuous	6.08 aB	8.33 aA	4.16 aC

[1]Tukey test at 5% level of significance

Comparing three scenarios, a statistical difference in the effective width exists between static grid and the rest of the scenarios evaluated in this study. Nevertheless, there was no difference for radial static and kinematic scenarios, suggesting that the radial static method can be an alternative for traditional tests of fertilizer machine. In addition, results also suggest that the test can be conducted under static indoor conditions making possible to recover the material effectively.

Overall, the transversal distribution uniformity of spreaders used for fertilizer and lime distribution is dependent on the quality and physical condition of the product utilized. Another limitation is the high doses of material applied in the trial fields, resulting in a greater accumulation of material in the distribution point, what causes that less material could be applied at longer distances from that point.

CONCLUSIONS

The average relative error of 21.61% was observed between kinematic and static grid scenarios. The lowest error (3.27%) was observed between kinematic and radial static scenarios. Radial static scenario overestimated the material application rate, while other scenarios underestimated this value.

There was a high variation among replicates, what represents a need of further assessment. Using Tukey test at 5% level of significance, some statistical differences were observed depending on the trajectory. Overall, radial static method can be an alternative for traditional tests of machines used for field applications.

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Appendix-A

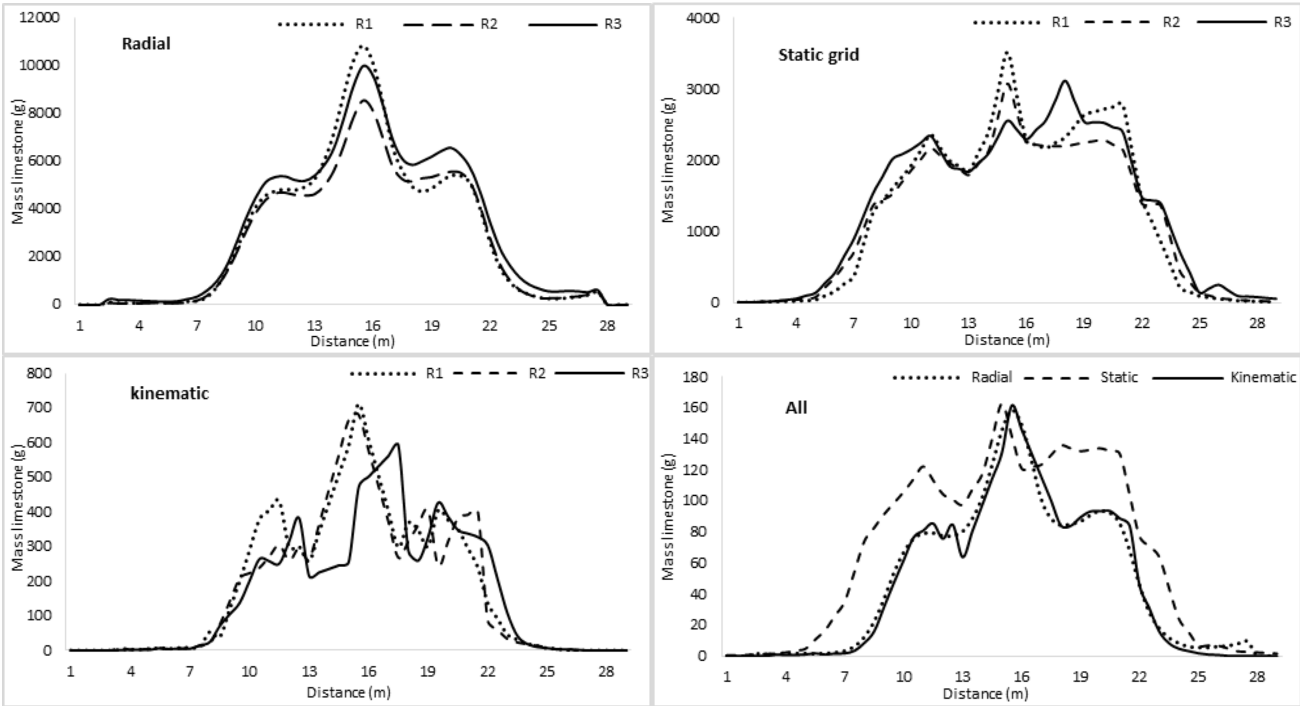

Figure 4. Profile of distribution of the three repeats (R1, R2, R3) for each type of test and comparison of the profile of each assay using the normalized average of repetitions of each test (last figure).

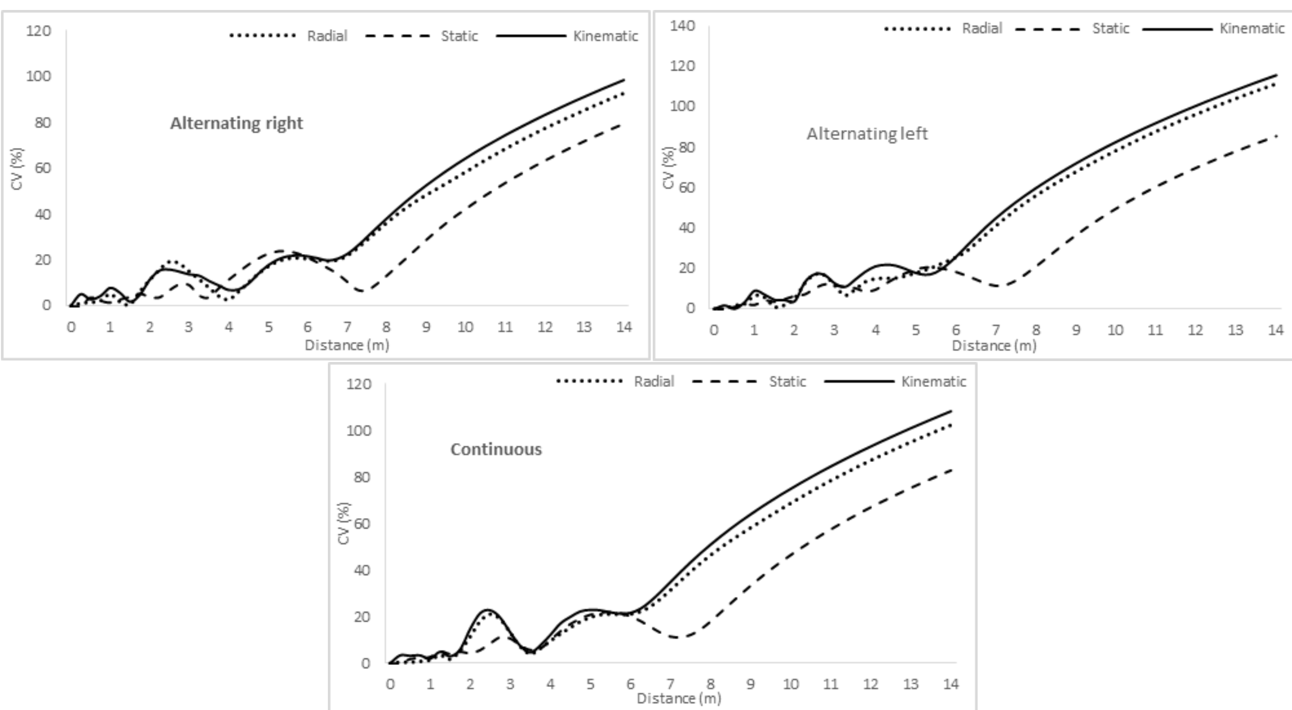

Figure 5. Comparing the coefficient of variation values (CV) between the three tests for the three distribution systems.