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Critical velocity of solid mineral fertilizers in a vertical upward airstream and repose angle

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Abstract. Critical velocity of mineral fertilizers in airstream is important not only at the application of fertilizers by spreaders but also at combine of fertilizing and sowing. The knowledge of angles of repose is important to design hoppers on spreaders for solid mineral fertilizers. Critical velocities for six solid mineral fertilizers were measured in the vertical aspiration duct of a laboratory sorting machine. Variation curves were constructed for particular fertilizers and the mean critical velocity of fertilizers (velocity of uplift) was computed. The mean critical velocity of fertilizers was between 8.53 and 12.43 m s^{-1}. The lowest critical velocity was found out in the fertilizer UREA 46%, the highest in the fertilizer LAV. Statistical significance of differences in the critical velocity of fertilizers was assessed. Angles of repose of eight solid mineral fertilizers were also measured and statistical significance of differences was evaluated. The highest values of repose angle were determined for potassium salt and ammonium sulfate (35.9° respectively 34.9°), the lowest values for UREA and LAV (28.7° respectively 29.6°). The obtained results extend information applicable to an assessment of parameters of the operation quality of spreaders during mineral fertilizer application.

Key words: mineral fertilizers, variation curves, repose angle.

INTRODUCTION

Aerodynamic properties of mineral fertilizers are important not only at the application of these fertilizers by pneumatic spreaders but also at simultaneous fertilizing and sowing. Unevenness of the aerodynamic properties is one of the causes of undesirable fluctuations in the quality of mineral fertilizer application by spreaders, especially at a large operating width of these machines. Aerodynamic properties are mainly related with the properties of fertilizers (bulk density, granulometric composition, shape), and also with the parameters of flowing air while the airstream evenness is important.

The evaluation of aerodynamic properties of solid mineral fertilizers is based on the studies of physical and aerodynamic properties of agricultural material and products (Stroshine, 2000; Csizmazia & Polyak, 2001). Methodically, the measurement of aerodynamic properties of solid mineral fertilizers employs the findings of Stroshine (2000), Güner (2007), Russo (2011). Many literature sources dealt with aerodynamic properties of seeds (Srivastava et al., 2006).

The objective of experiments was to determine critical velocities of some solid mineral fertilizers and to assess statistical significance of differences. Angles of repose of solid mineral fertilizers were measured and statistical significance of differences in the angles of repose was assessed. The knowledge of angles of repose is important for designing hoppers for solid mineral fertilizers. The bottom of the hoppers of solid mineral fertilizer spreaders should be designed so that fertilizers would move fluently to a metering port.

MATERIALS AND METHODS

To measure critical velocities of solid mineral fertilizers a K-293 laboratory air sorting machine was used with the adjustable through-flow volume of air flowing in the vertical aspiration duct. Samples of 800 g in weight were weighed for each mineral fertilizer. At the gradually increasing velocity of the upward airstream in the vertical aspiration duct of the sorting machine fertilizer particles with different aerodynamic properties were separated from each other. Four repeated measurements were done in all samples of mineral fertilizers.

For the chosen groups of solid mineral fertilizers the measured values were used for plotting variation curves. The values of the mean critical velocity (mean velocity of uplift) of mineral fertilizers were computed:

$$v_{krit} = \frac{\sum (m_i \cdot v_i)}{m} \ \text{(m s}^{-1}\text{)} \qquad (1)$$

where v_{krit} – mean critical velocity (mean velocity of uplift) of fertilizers (m s^{-1}); m_i – weight of the respective class (g); v_i – velocity of the class centre (m s^{-1}); m – weight of mineral fertilizer sample (g).

Assuming the normal distribution of frequencies, the mean critical velocity is approximately identical with the most numerous class of variation curve.

The Statistica 10 programme was used for processing measured data. Variation curves of critical air velocities for particular fertilizers were constructed and mean values and error bars are shown. Descriptive statistics of critical vertical air velocities are also presented. The analysis of variance was used to assess the statistical significance of differences in the mean values of critical velocities. A graph of critical velocities was constructed where significant differences are designated by different letters.

The angles of repose of solid mineral fertilizers were measured in a special measuring trough when fertilizers were poured into a metal trough which had the shape of the bottom of a hopper in a mineral fertilizer spreader. Using a hydraulic cylinder the metal trough was gradually tilted until the fertilizer started sliding and the trough was emptied due to gravity. Five repeated measurements of repose angles were done in samples of mineral fertilizers. Descriptive statistics were determined also for the angles of repose of solid mineral fertilizers and statistical significance of differences in the angles of repose was represented in a graph.

The six most used fertilizers in farms in the Czech Republic were chosen for the measurement of critical velocities in a vertical upward airstream. Also repose angles were measured for these fertilizers. As well the repose angles were measured for two other fertilizers, where difficulties in continuous movement in the hoppers of spreaders sometimes occur. Size fraction of fertilizers after sieving on sieves are in the Table 1.

The shape of six tested fertilizers is shown in the photographs in Fig. 1. The other two fertilizers had a crystalline structure (magnesium sulfate and ammonium sulfate.

Table 1. Representation (distribution) of fertilizers size fractions (%)

Apertures of the sieves	UREA 46%	LAV[x]	Magnesium sulfate 32–16	AMOFOS	NPK 15-15-15	Superphosphate	Ammonium sulfate 20%	Potassium salt 60%
1 mm	3.8	0.0	0.3	0.0	0.0	0.0	37.1	69.1
1–2 mm	63.6	0.0	2.1	0.2	2.3	0.2	43.6	25.7
2–3 mm	32.5	2.3	26.7	16.1	32.3	10.7	17.4	5.0
3–4 mm	0.1	48.3	45.2	70.3	40.2	46.1	1.8	0.2
4–5 mm	0.0	47.1	25.7	13.4	22.9	42.3	0.1	0.0
> 5 mm	0.0	2.3	0.0	0.0	2.3	0.7	0.0	0.0

[x] *LAV – Ammonium nitrate with calcite.*

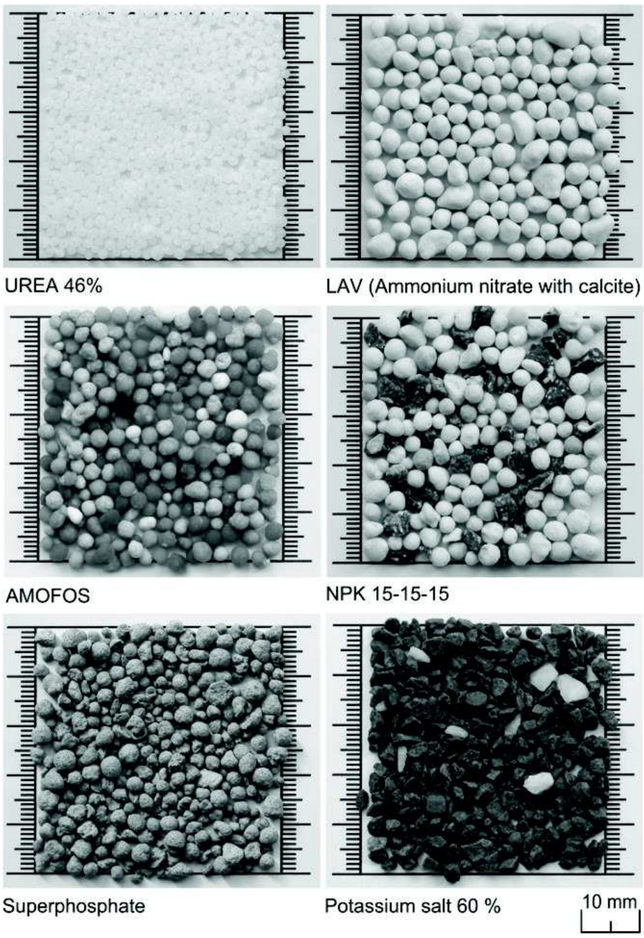

Figure 1. Shape of six tested fertilizers – shape of granules, crushed mineral (potassium salt 60%).

Properties of mineral fertilizers were measured in laboratory conditions in accordance with recommendation (Decree No. 273/1998). The air temperature was 18° C, relative air moisture was 38%. Moisture content and bulk density of tested mineral fertilizers at the time of laboratory measurements are given in the Table 2.

Table 2. Moisture content and bulk density of mineral fertilizers

Fertilizer	Moisture (% weight)	Bulk density (g cm^{-3})
UREA 46%	0.29	0.72
LAV (Ammonium nitrate with calcite)	0.18	0.97
Magnesium sulfate 32–16	3.19	0.98
AMOFOS	0.32	0.97
NPK 15-15-15	2.96	1.07
Superphosphate	0.76	1.22
Ammonium sulfate 20%	0.20	0.86
Potassium salt 60%	0.17	1.05

Conditions in real work situation during spreading of mineral fertilizers can be within a wide range (e.g., from mild frost in early spring to the high temperature at the end of spring).

RESULTS AND DISCUSSION

Table 3 shows descriptive statistics of critical vertical velocities for the tested mineral fertilizers. Coefficient of variation (CV) as the relative value of the measure of dispersion of values around the mean value makes it possible to compare various sets of measured data. Coefficients of variation are from 0.32 to 1.42%. The values of the minimum and the maximum define the categories statistical data sets belong to. Asymmetry from the Gaussian normal distribution is expressed by the coefficient of skewness. The condition of data normality is satisfied if the interval of skewness lies between the values -2 and 2. Normality of distribution was fulfilled, so one of the basic assumptions for the use of most statistical analyses was satisfied.

Table 3. Descriptive statistics of critical vertical velocities (m s^{-1})

Indicator	UREA 46%	LAV	AMOFOS	NPK 15-15-15	Super-phosphate	Potassium-salt 60%
Mean (m s^{-1})	8.53	12.43	11.94	12.42	12.24	10.22
Median (m s^{-1})	8.51	12.44	11.94	12.42	12.21	10.26
Standard deviation (m s^{-1})	0.12	0.04	0.12	0.06	0.10	0.11
Coefficient of variation (%)	1.42	0.32	0.99	0.48	0.79	1.06
Skewness	0.89	-0.93	0.10	0.05	1.08	-1.54
Difference max-min (m s^{-1})	0.29	0.09	0.26	0.14	0.22	0.24
Minimum (m s^{-1})	8.40	12.38	11.82	12.35	12.15	10.06
Maximum (m s^{-1})	8.69	12.47	12.08	12.49	12.37	10.30

Figs 2–4 illustrate variation curves of the tested fertilizers with the percentages of particular fractions at an increasing velocity of the vertical airstream. The scales of axes are identical in all figures. In graphs mean values and error bars for standard error are indicated. These graphs clearly indicate differences between fertilizers with respect to their aerodynamic properties.

When determining the properties of mineral fertilizers in an upward airstream, statistical significance of differences in the mean values of critical velocities was assessed by the analysis of variance. An *F-test* was performed which indicated statistically significant differences in the values of critical air velocities for the particular solid mineral fertilizers.

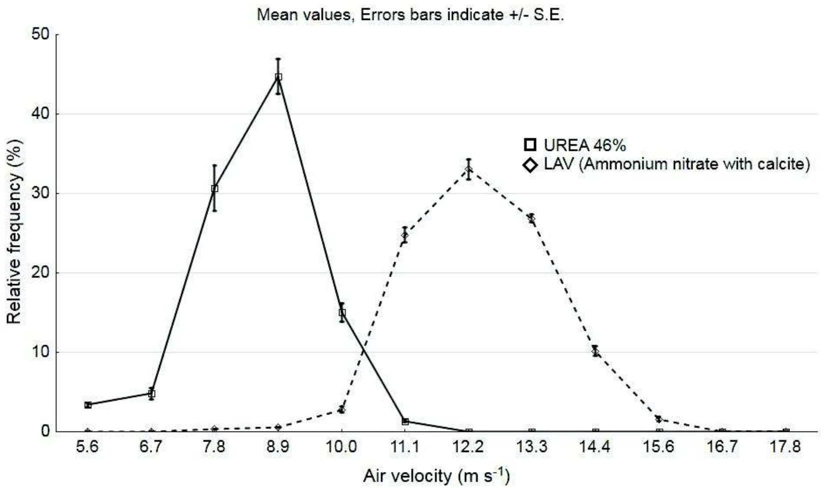

Figure 2. Variation curves for fertilizers UREA and LAV.

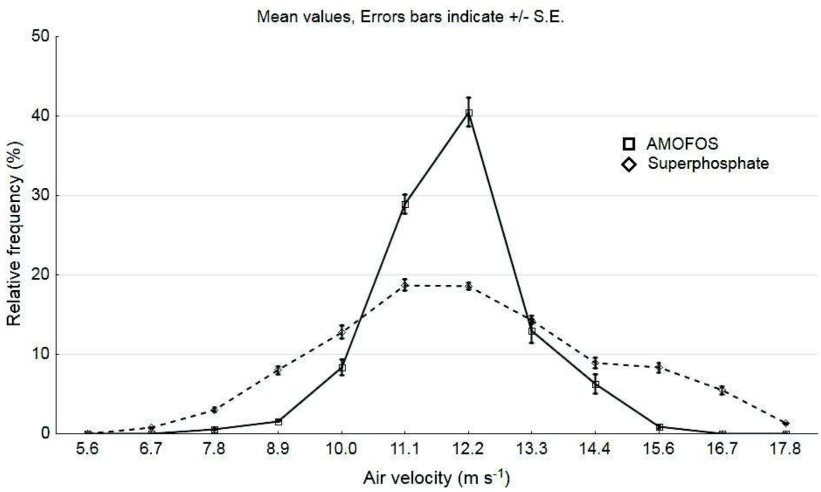

Figure 3. Variation curves for fertilizers AMOFOS and Superphosphate.

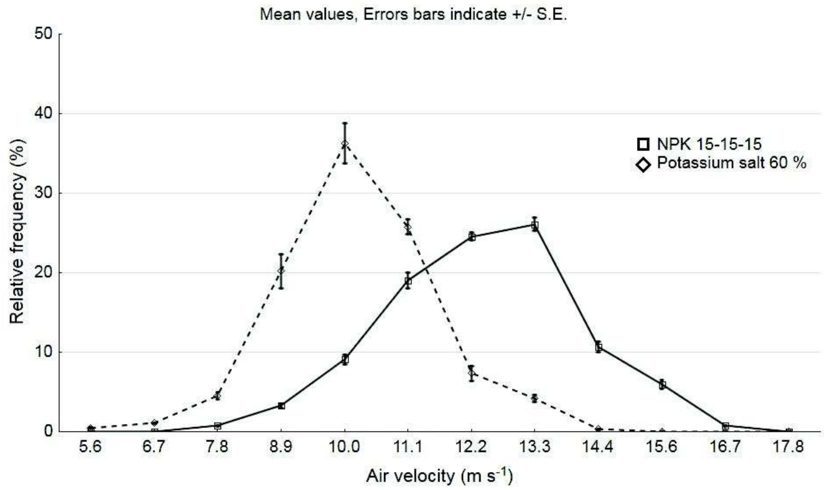

Figure 4. Variation curves for fertilizers NPK and Potasium salt.

A crucial assumption of the analysis of variance is the homogeneity of variances for all variants. The performed test revealed that the result of the analysis of variance is not burdened with an error that would be caused by the non-homogeneity of variances.

The graph in Fig. 5 transparently shows critical velocities for the particular fertilizers. Statistically significant differences are designated by different letters. There are no statistically significant differences between fertilizers with the same letter. As for critical velocities, statistically in significant differences are between the fertilizers LAV, NPK and Superphosphate (the values from 12.24 to 12.43 m s^{-1}). The lowest mean critical velocity was found out in the fertilizer UREA 46% (8.53 m s^{-1}), the second lowest critical velocity was observed in potassium salt 60% (10.22 m s^{-1}).

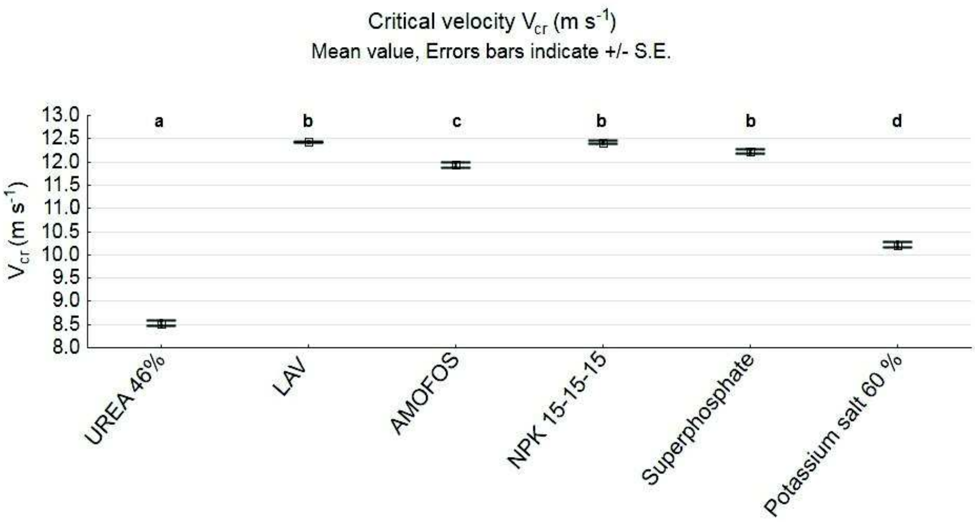

Figure 5. Graph of critical velocity – significant differences are indicated by different letters (a, b, c, d).

It was measured altogether 8 fertilizers for a comparison of the angles of repose. Table 4 shows average values of the angles of repose, Fig. 6 documents the statistical significance of differences in the angles of repose. Fertilizers are arranged in the graph according to increasing values of the angles of repose. This property of mineral fertilizers was also found to show statistically significant differences between some fertilizers. The highest values of repose angle were determined for potassium salt and ammonium sulfate (35.9° respectively 34.9°), the lowest values for UREA and LAV (28.7° respectively 29.6°).

Table 4. Repose angle of solid mineral fertilizers

Fertilizer	Repose angle (°)
UREA 46%	28.7
LAV	29.6
Magnesium sulfate 32–16	32.2
AMOFOS	32.6
NPK 15-15-15	32.9
Superphosphate	33.5
Ammonium sulfate 20%	34.9
Potassium salt 60%	35.9

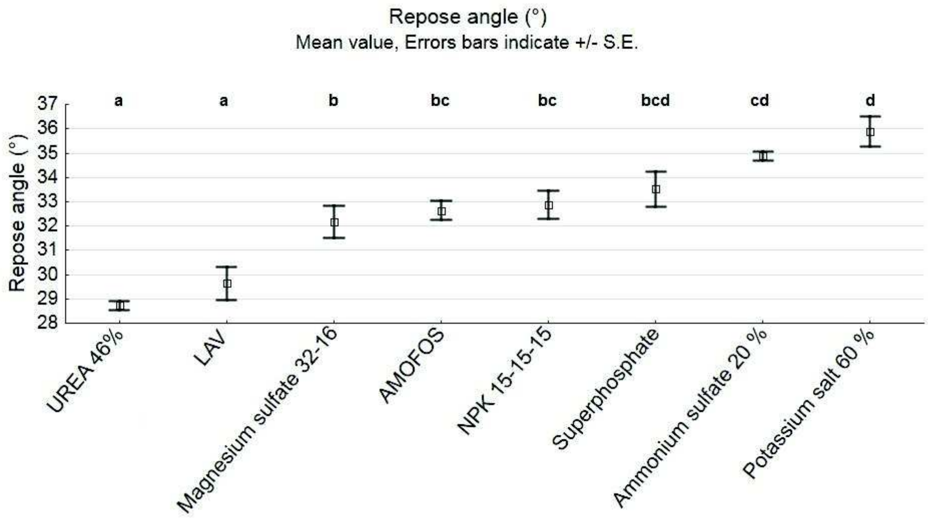

Figure 6. Repose angle of mineral fertilizers – significant differences are indicated by different letters (a, b, c, d).

The results confirm the information in literature about the properties diversity of mineral fertilizers and relating these properties with quality fertilizers application (Csizmazia, 2000; Hrůza et al., 2007; Krupička et al., 2015). Aerodynamic properties of solid mineral fertilizers can be assessed as well considering the aerodynamic properties of seeds and other agricultural material and products (Stroshine, 2000; Csizmazia & Polyak, 2001).

Measurement of critical velocity and repose angle allowed to compare the properties of selected solid mineral fertilizers, which are supplied to the farms in the Czech Republic. It is assumed that similar values of fertilizer critical velocity will have similar quality indicators of spreading when using the centrifugal and pneumatic mineral fertilizer spreaders (LAV, NPK 15-15-15, superphosphate).

Spreading in smaller working width of the centrifugal fertilizers spreaders can be assumed for fertilizers with a substantially lower of critical velocity (UREA 46%, potassium salt 60%) than for other tested fertilizers. The measurement results of critical velocity are an argument for preferential use of pneumatic spreaders instead the centrifugal spreaders.

CONCLUSIONS

Statistical evaluation of critical velocities of some solid mineral fertilizers revealed the degree of unevenness of aerodynamic properties of these fertilizers. Detailed knowledge of aerodynamic properties of materials that are applied through an airstream (solid mineral fertilizers, seeds) can be a contribution to an increase in the application precision, which is in line with objectives of precision agriculture.

Different aerodynamic properties of mineral fertilizers are one of the reasons of unevenness during application of mineral fertilizers mainly by centrifugal spreaders. When working width of the centrifugal spreaders is become larger then more problems with unevenness of spreading occur. Spreaders with jibs and the air-operated of fertilizers to the spreading tail pipes are preferred for a large working width (e.g. 36 m).

The bottom of the hoppers for tested solid mineral fertilizer spreaders should be designed with a greater inclination angle than 36°.

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