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The effect of granulometric structure and moisture of fertilizer on its static strength

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Abstract

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During the load of vertical static force the strength limit of individual fertilizer particles was studied in relation to the fertilizer moisture content and granulometric composition. The experiment was conducted for the fertilizer damage at the different level of fertilizer moisture content and particle size groups. The result of the first part indicates the need to point out the differences of static strength between prilled and granular fertilizers. Both types of prilled fertilizers reached from 3 to 8 times lower values of static strength than standard granular fertilizers. The theses above point out the need for more caution during manipulation, storage and application of prilled fertilizers, the quality of which may be affected at some point by the greater extent of static load. The second part of the study was focused on the effect of moisture and granulometric fraction of fertilizer on static strength of fertilizer. For all tested fertilizers the statistical difference was observed for both of variation factors. Their mutual ratio of the effect is however different for each individual fertilizer. This fact may be interpreted as the dependence of the quantity of water that the individual fertilizers are able to absorb. This amount was influenced by very different types of fertilizers' hygroscopicity. The interaction of both factors at the same time was not confirmed for any fertilizer tested.

Keywords: particle distribution; properties of fertilizer; hygroscopicity; static load; static strength

Fertilizers are currently among the most important commodities entering into the process of crop production in agro production sector (Bielek 1996; Lou et al. 2010; Michalík 2010). Ložek (2000) stated that fertilizers in terms of composition and function of yield-forming elements affect the soil profile and therefore following Lawrence and Yule (2005) they contribute to the formation of the final product. By inappropriate application process, however, contamination of surface and groundwater can be caused (Fulton et al. 2003; Joshi et al. 2006; Nozdrovický et al. 2009), this is particularly undesirable in the vulnerable areas (Grift, Kweon 2006; Jackson et al. 2009). Problems in the area of fertilizers application as well as methods of storage and the use of fertilizers are covered by the EU directive No. 91/676/EHS. The proper application of fertilizers is affected by many factors (Macák 2009), which includes also machinery for fertilizers distribution on the surface of the field (Srivastava et al. 1993; Macák, Nozdrovický, 2010; Macák et al. 2011). According to the mentioned authors and Jobbágy and Árvay (2007), the quality of work of these machines is affected by the type of individual distribution system, individual technical solution of manufacturer alone and, last

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but not least, by the physical and mechanical properties of the applied fertilizers. Hofstee (1993) includes among them also static strength of fertilizers. In addition, it was stated that the fertilizer property is also affected by other factors, however those are specific for every type of fertilizer itself.

The aim of the study was focused on the effects of two selected properties of fertilizer and their interaction with static strength of fertilizer.

MATERIAL AND METHODS

Static strength of fertilizers is characterised as a force which affects the granules in vertical as well as in horizontal direction until their destruction. The measurements were focused on the assessment of change of two factors to the value of this limit force: (a) particle size of fertilizer – represented by different fraction sizes of particle size distribution; (b) moisture of fertilizer.

The methodology follow the Slovak standards STN CR 12333:2005 and STN 654824:2005. Measurement procedure was based on observation of force necessary to crush one granule of fertilizer. This force was measured by device TMZ-3U Electronic (Micro Sensor s.r.o., Bechyně; Czech Republic) (Fig. 1) in laboratories of the Research Institute of Chemical Technology, Bratislava, Slovakia, and in Duslo a.s., Šala, Slovakia. The principle of using the selected device for measurement of point strength of granules is based on two basic types: (a) measurement by constant force; (b) measurement by constant speed of valve movement what was used in the procedure used in our study (Fig. 2). The speed of valve movement was set on 10 mm/min.

(a) (b)

Fig. 1. Device TMZ-3U Electronic for measurement of the static strength (a) and detail of the valve vertical movement during pressing of the fertilizer particle (b)

Evaluated relationships and comparisons were conducted on two types of granulated and two types of prilled fertilizers. The basic characteristics of individual types of fertilizers used in tests are shown in Table 1.

Measurement procedures

The measurement procedure was as follows:

(a) Sorting of the fertilizers on individual fractions according to the particle size distribution. Urea, prilled fertilizer consists of significantly low percentage of weight from particles greater than

Table 1. An overview of tested fertilizer characteristics

Source of variability	*F*-test	*P*-value	F_{crit}	Variance (%)	*F*-test	*P*-value	F_{crit}	Variance (%)
	Ammonium nitrate				Urea			
Moisture content	84.911	7E-23	3.0804	57.88	34.395	1E-07	3.9739	23.50
Granulometric fraction	3.5883	0.0161	2.6887	3.67	11.588	3E-06	2.7318	23.75
Interaction	0.8001	0.5719	2.1837	1.64	1.7327	0.1679	2.7318	3.55
Together	–	–	–	36.81	–	–	–	49.20
Sum	–	–	–	100.00	–	–	–	100.00
	NMgS				Duslofert EXTRA			
Moisture content	56.887	1E-18	3.0632	39.6	44.302	1E-15	3.0589	23.78
Granulometric fraction	8.073	7E-06	2.4387	11.2	44.045	3E-20	2.6674	35.45
Interaction	0.7529	0.6447	2.0076	2.1	1.3236	0.2503	2.1621	2.13
Together	–	–	–	47.0	–	–	–	38.64
Sum	–	–	–	100.00	–	–	–	100.00

F_{crit} – critical value for used test (*F*-statistics)

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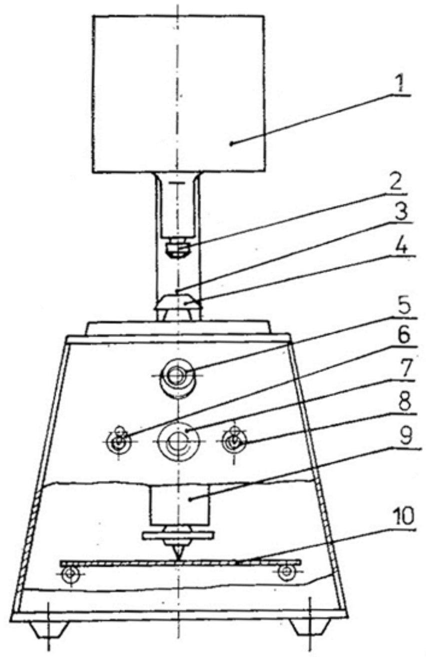

Fig. 2. Principle basic scheme of device for measuring of the static strength

1 – mechanism of equipment, 2 – stamp, 3 – examined particle of fertilizer, 4 – working table, 5 – indicating lamp, 6 – switch, 7 – setting key, 8 – switch, 9 – differential transformer, 10 – spring

3.15 mm and therefore the measurement of this particle size fraction was omitted. Following the measurement procedure continued according to standard STN 65 4823:2005 – Method for determination of particle size distribution.

(b) The distribution of samples from each of the particle size distribution in four parts. Each sample was created as a division from initial amount of fertilizer with weight of 150 g. Each sample then consists of 20 granules and was tested with one replication.

(c) Three samples of each selected particle size distribution were placed in the vacuum desiccators which contained distilled water as a source of moisture. The evaporation of water to the space of desiccators increased the partial pressure of water vapour above the inserted samples; therefore fertilizer absorbs the moisture and increases its moisture content. The amount of moisture that fertilizer taken was regulated on the length of time basis in which the samples were stored in a desiccator. Fertilizer samples were weighed before inserting in the desiccators and straight after their removal from it with accuracy of 0.0001 g.

(d) The particles of the fertilizer samples were then mechanically pressed by using of special device designed for measurement of static point resistance of fertilizers TMZ-3U Electronic (Fig. 1b). The measurement was conducted with constant valve speed movement of 10 mm/min with vertical direction. The device was properly calibrated with overall accuracy of 0.27%.

(e) Statistical analysis and comparisons of individual fractions then followed.

RESULTS AND DISCUSSION

The Fig. 3 shows the static strength of each fertilizer in the form of a box plot. Moisture of samples (bottom of x axis) is labelled from P to P3. Sample P contained the lowest level of humidity which was not increased by inserting into desiccators. Thus, the value is called initial moisture which fertilizer contains as a final product of manufacturer. The P1 to P3 values represent the moisture volume of fertilizer that was kept for a certain amount of time in desiccators, compelled humidity increase; sample P1 was left in desiccators for the shortest time and gradually the time increased up to sample P3 that was kept in desiccators for the longest time. The time and moisture content of the fertilizer samples are shown in Table 2.

On the top of x axis individual particle size fractions of fertilizer are shown and they are assigned to the corresponding values of static strength in Newton's (N) (y axis) of individual samples P to P 3 for each fraction.

Hofstee (1992) stated that handling and spreading of fertilizer is affected by the physical properties of the particles, and so knowledge of these properties is helpful in understanding fertilizer handling and use. Methods for measuring the coefficient of friction, the coefficient of restitution, the aerodynamic resistance coefficient and the breaking force (particle strength) of fertilizers were discussed. Measuring devices for the four properties were developed and their characteristics were described. The results of experiments with these devices were presented. Partial compliance of the study results was observed with slight differences that were probably caused by sample compositions and slight differences in used methodologies (Macák et al. 2009).

From the shown evaluation and comparison of sample series (Fig. 3) a partial correlation between static strength and moisture of the fertilizer can be

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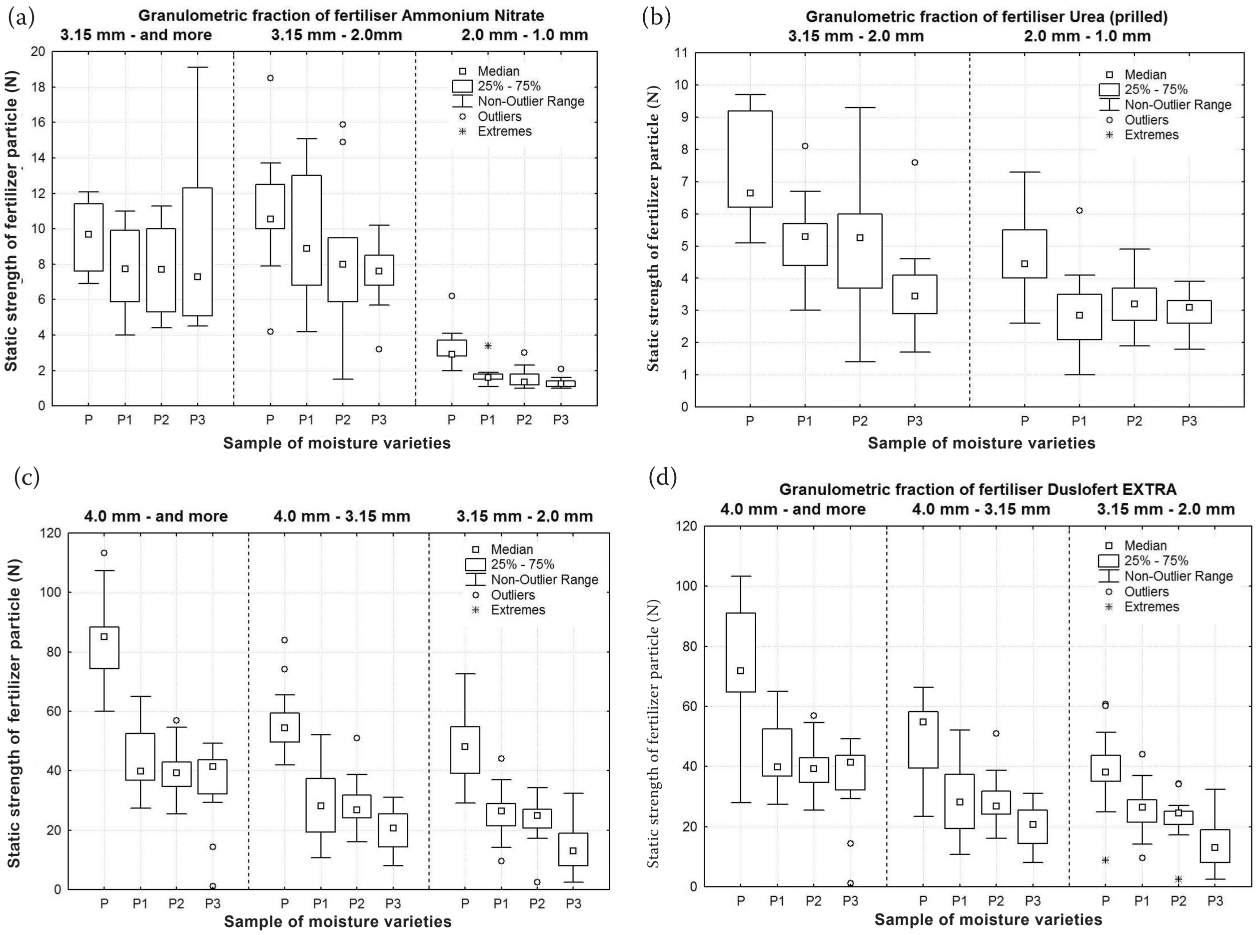

Fig. 3. Static strength of fertilizers Ammonium Nitrate (a), Urea prilled (b), NmgS (c) and Duslofert Extra (d)

seen. It is represented by a decreasing value of critical forces required for the destruction of fertilizer granules and for each of the examined type of fertilizer, which means that with increasing moisture of the fertilizer content the static strength of fertilizer granules is decreasing. According to Hofstee (1992) the coefficient of friction is influenced to a minor extent by the velocity relative to the friction surface layer. There was almost no influence of normal load but a significant effect of fertilizer type, friction surface layer and environmental conditions. The coefficient of restitution measurements showed a large effect of the impact surface and smaller effects of particle diameter and fertilizer type. A large difference was found between two methods for measuring the aerodynamic resistance coefficient. A new shape parameter was introduced in this paper, as a parameter to determine the aerodynamic resistance of fertilizer particles. Coarser particles were shown to have a higher aerodynamic resistance coefficient than particles with smooth surface texture. The breaking force measurements showed that the relationship between strength and particle size depended on the fertilizer type.

Furthermore, it is possible to observe a decreasing value of static strength values of fertilizers in decreasing the size fractions of fertilizers in individual moisture from P to P3 with exception of prilled Ammonium nitrate. In this case, it is possible to see completely opposite comparison between the fractions of "3.15 mm and more" and "3.15–2.0 mm". This phenomenon is caused by the character of prilled fertilizers in terms of which the particles are completely hollow inside (Ji 2006). This type of fertilizer is composed by particles with fractions "3.15 mm and more" which are not characterized by full spherical surface and therefore consist of holes and cracks. This is the reason why this fraction is weaker in static strength than a fraction with smaller dimensions (3.15–2.0 mm) where the particles do not have this surface defects.

From box plot outputs it is also possible to observe that granulated types of fertilizers have a greater static strength in comparison with prilled

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Table 2. Fertilizer particles moisture content and duration of the moistening

Fertilizer type	Parameter	Fertilizer sample			
		P1	P2	P3	P4
Ammonium nitrate	fertilizer moisture content (%)	0.67	1.62	1.57	2.01
	moisturizing duration (h)	–	1.5	2.0	2.5
Urea	fertilizer moisture content (%)	0.56	1.17	1.43	2.11
	moisturizing duration (h)	–	1.5	2.0	2.5
NMgS	fertilizer moisture content (%)	9.74	9.76	9.80	9.81
	moisturizing duration (h)	–	0.5	1	1.5
Duslofert EXTRA	fertilizer moisture content (%)	0.37	0.44	0.45	0.50
	moisturizing duration (h)	–	1	1.5	2

fertilizers which is represented also by median values of static strength while for granulated fertilizers they reach from 3 to 8 times greater values in comparison with prilled fertilizers. To determine the ratio of the effect of the studied parameters (size of granulometric fraction, moisture of fertilizer) on static strength of fertilizer two-way analysis of variance (ANOVA) was used.

The statistical analysis of measured value was conducted in MS Excel spreadsheet. The results of two-way analysis of variance are shown in Table 3.

Based on the built-in test *F*-multifactor analysis of variance it started from the conditions that if the *F*-test value is lesser than the critical F_{crit} value ($F < F_{crit}$) than the tested factor, or interaction of selected factors, do not affect the observed phenomenon. Based on this condition, the null hypotheses were defined for all of the type of fertilizers since the same phenomenon was observed for all of the fertilizers. The null hypothesis assumes H_0: There is no effect of selected factor (moisture of fertilizer, size of particles and shared effect of these factors) on static strength of particular fertilizer. The level of significance was the same for all types of fertilizers in the analysis ($\alpha = 0.05$).

Since the calculated value of *F*-test is greater than the critical value F_{crit} (84.9 > 3.08), the null hypothesis can be rejected and argument can be accepted that the moisture of fertilizer affects the static strength of fertilizer ammonium nitrate. In the case of granulometric fraction it shows the same condition $F > F_{crit}$ (3.58 > 2.68), thus the null hypothesis can be rejected and argument can be accepted that effect of fraction size of fertilizer ammonium nitrate and static strength of its particles exists. The effect of both factors together was not proved (0.8 < 2.18).

For Urea fertilizer and moisture factor the inequality looks like $F > F_{crit}$ (34.39 > 3.97) and for granulometric fraction factor the inequality looks like $F > F_{crit}$ (11.59 > 2.73). Based on the mentioned inequalities the null hypothesis H_0 can be rejected and the relationship of both factors on static strength of fertilizer particles can be confirmed. The interaction of both factors together was not observed ($F < F_{crit}$; 1.73 < 2.73).

For granulated fertilizer NMgS the relationship of moisture ($F > F_{crit}$; 56.89 > 3.06) and the size of fertilizer particles ($F > F_{crit}$; 8.07 > 2.44) on static strength of observed fertilizer were proved again. Simultaneously, interaction of both factors does not have a statistically significant effect.

For the last tested fertilizer it can be also concluded that there exists an effect of the observed factors on the extent of destructive force (static strength of fertilizer particles) because in both cases the condition $F > F_{crit}$ is fulfilled. Interaction of both factors together with this fertilizer do not have a statistically significant effect on observed phenomenon ($F < F_{crit}$).

The values of variance display the weight of individual factors on static strength of fertilizers. These values are calculated as the share of SS (Sum of Squares) of individual factor to the total value.

Hofstee (1990) concluded that the performance of fertilizer distributors and hence the evenness of the spread pattern depends to a large extent on the physical properties of the fertilizer. The influence of physical properties on the particle motion in the fertilizer distributor and through the air was discussed. Particle motion in the fertilizer distributor device was discussed for both spinning disc and reciprocating spout fertilizer distributors. Five important properties which affect particle motion was reviewed, namely particle size and particle size distribution, coefficient of friction, coefficient of restitution, aerodynamic resistance, and par-

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ticle strength. The latter was indirectly related to the particle motion. The coefficient of friction, the aerodynamic resistance, and the particle size and particle size distribution are the most important because they influence the spread pattern to a large extent. The influence of the coefficient of restitution is not very clear and the particle strength is important in relation to quality requirements that fertilizers have to meet (Walker et al. 1997).

Moreover, Allaire and Parent (2004) concluded that bulk density, granule density, and the angle of repose all decreased with increasing organic matter content, while porosity and tensile strength increased with organic matter content. Bulk density and tensile strength were also significantly affected by granule size distribution. Additionally, density, porosity, tensile strength, and the angle of repose were all affected by the initial water content. There were significant correlations between the static physical properties and these could be used as preliminary predictors of other properties.

CONCLUSION

The application of fertilizers is among challenging operations of crop production on the farms. The application quality of fertilizers is affected by the machinery but also by fertilizers themselves with their properties that need to be maintained upon storage in the required quality.

The result of the first part indicates the need to point out the differences of static strength between prilled and granular fertilizers. Both types of prilled fertilizers reached from 3 to 8 times lower values of static strength than standard granular fertilizers. The theses above point out the need for more caution during manipulation, storage and application of prilled fertilizers, whose quality may be affected at some point by the greater extent of static load. During their application it is preferable to use the machinery with pneumatic spreader system.

The second part of the study was focused on the effect of moisture and granulometric fraction of fertilizer on static strength of fertilizer. For all tested fertilizers, the statistical difference was observed for both variation factors. Their mutual ratio of effect is however different for each individual fertilizer. This fact may be interpreted as the dependence of the quantity of water that the individual fertilizers are able to absorb (Ji 2006) . Thus, this amount was influenced by very different types of fertilizers's hygroscopicity. Therefore, relatively high residual variability for all fertilizers occurs. The interaction of both factors at the same time was not confirmed for any tested fertilizer.

In the future, it is necessary to develop new technical possibilities of application machines and adapt production technologies of fertilizers to the level where they are able to reach the requirements of accurate and efficient system of differentiated fertilization in precision agriculture.

References

Allaire S.E., Parent L.E. (2004): physical properties of granular organic-based fertilisers, Part 1: Static Properties. Biosystems Engineering, 87: 79–87.

Bielek P. (1996): Ochrana pôdy – Kódex správnej poľnohospodárskej praxe vSR. Bratislava, Ministerstvo pôdohospodárstva SR.

Fulton J.P., Shearer S.A., Stombaugh T.S., Higgins S.F. (2003): Comparison of variable-rate granular application equipment. In: ASAE Paper No. 031125. St. Joseph, ASAE.

Grift T.E., Kweon G. (2006): Development of a uniformity controlled granular fertilizer spreader. Paper No.: 061069, UIUL Number: 2006-7017. In: ASABE Meeting Presentation. American Society of Agricultural and Biological Engineers.

Hofstee J.W. (1993): Physical properties of fertilizer in relation to handling and spreading. [Thesis.]. Wageningen University.

Hofstee J.W. (1900): Handling and spreading of fertilizers Part 1: Physical properties of fertilizer in relation to particle motion. Journal of Agricultural Engineering Research, 47: 213–234.

Hofstee J.W. (1992): Handling and spreading of fertilizers: Part 2, physical properties of fertilizer, measuring methods and data. Journal of Agricultural Engineering Research, 53: 141–162.

Jackson J. et al. (2009): UK greenhouse gas inventory, 1990 to 2007 annual report for submission under the framework Convention on Climate Change. AEA Technology.

Ji H.H. (2006): Moisture absorption of granular fertilizer and its distribution characteristic by a pneumatic applicator. St. Joseph, ASABE. Paper No: 061072.

Jobbágy J., Árvay J. (2007): Stanovenie variability zásoby živín na pozemku ako vstupných hodnôt pre variabilnú aplikáciu. In: Proceedings from IX. Medzinárodná vedecká konferencia mladých, Oct 10–11, 2007, Nitra.

Joshi M., Giannico N., Parish R.L. (2006): Technical note: Improved computer program for spreader pattern analysis. Applied Engineering in Agriculture, 22: 799–800.

doi: 10.17221/31/2016-RAE

Lou J., Deklein C.A.M., Ledgard S.F., Saggar S. (2010): Estimation of nitrous oxide emission from ecosystems and its mitigation technologies. Agriculture, Ecosystems & Environment, 136: 282–291.

Lawrence H.G., Yule I.J. (2005): Accessing spreader performance for variable rate fertiliser application. In: ASAE Meeting Presentation. Paper No.: 051117.

Ložek O. (2000): Efektívnosť hnojenia vybraných poľnohospodárskych plodín priemyselnými hnojivami. Agrochémia, IV: 4–6.

Macák M. (2009): Vlastnosti granulovaných priemyselných hnojív a ich vplyv na funkciu rozhadzovačov z pohľadu požiadaviek presného poľnohospodárstva. [PhD. Thesis.]. Nitra, SUA in Nitra.

Macák M. et al. (2009): Vplyv fyzikálno mechanických vlastností priemyselných hnojív na funkciu rozhadzovačov z pohľadu požiadaviek presného poľnohospodárstva. Prague, CULS Prague.

Macák M., Nozdrovický L. (2010): Bodová pevnosť priemyselného hnojiva v závislosti od veľkosti granulometrického zloženia a vlhkosti hnojiva. Acta Technologica Agriculturae, 12: 61–66.

Macák M., Nozdrovický L., Žitňák M. (2011): Vplyv granulometrického zloženia priemyselných hnojív na kvalitu práce rozhadzovača. Agrochémia, 51: 11-15.

Michalík I. (2010): Rozporné názory na aplikáciu priemyselných hnojív v podmienkach ekologického pestovania plodín. Agrochémia, 50: 25–26.

Nozdrovický L., Macák M., Findura P. (2009): Vplyv granulometrického zloženia priemyselných hnojív na priečnu rovnomernosť aplikácie. In: New Trends in Design and Utilisation of Machines in Agriculture, Landscape Maintenance and Environment Protection: Proceedings of the International Scientific Conference, Prague, May 5–7, 2009: 210–218.

Richter R., Hlušek J. (1996): Průmyslová hnojiva, jejich vlastnosti a použití. Prague, IVV MZe ČR.

Srivastava A.K., Goering, C.E., Rohrbach R.P. (1993): Chemical application. In: Engineering Principles of Agricultural Machines. St. Joseph, ASAE: 265–314.

Walker J.T., Grift T.E. Hofstee J.W. (1997): Determining effects of fertilizer particle shape on aerodynamic properties. Transactions of the ASAE, 40: 21–27.

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