MATHEMATICAL MODEL TO DESCRIBE OF SOME AMMONIUM NITRATE PHYSICAL PROPERTIES IN RELATION TO THE UNIFORMITY OF GRANULATED FERTILIZER APPLICATIONS

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Abstract: *This study analyzed the physical properties of a sample of ammonium nitrate: granules diameter (D), granules number (GN) by size classes according to their diameter, the total weight of the granules (TWG) on each size class, and respectively, the average weight of a granule (AWG) on each size class. The correlation analysis revealed very high positive correlation between AWG and D (r = 0.961) and high positive correlation between TGW and GN (r = 0.830). Negative correlations were recorded between GN and D (r = -0.744), AWG and GN (r = -0.796), AWG and TWG (r = -0.574), and respectively between TGW and D (r = -0.418). The distributions of the granules by size classes, and respectively the average weight of a granule according to diameter, were most accurately described by a smoothing spline model, under statistical safety conditions (confirmed by* ε_i*).*

Key words*: ammonium nitrate, granule size, size classes, smoothing spline model*

INTRODUCTION

Solid mineral fertilizers are salts that are characterized by a series of chemical and physical properties that refer to the content in the active substance, particle size, hygroscopicity, physiological reaction, salinity index [19], [2]. In relation to the particle size, the chemical fertilizers are classified into powder (contain particles with a diameter between 0.01 - 0.1 mm), crystallized (contain particles between 0.2 - 1 mm) and granulated (contain particles with a diameter between 0.5 - 5 mm) [30], [6].

Physical properties of the fertilizers vary depending on the type and assortment of fertilizers, the presence of the predominant NPK elements and the additional ones (Ca, Mg, S, and microelements), by the presence of organic matter or other components that are included in the granule constitution [2]. It has been found that there are certain relationships between the static physical properties of the granulated fertilizers, and these relationships can be used as models for partial prediction of other properties or properties of the fertilizers [2].

Hofstee and Huisman (1990) [19] considered five physical properties of granular fertilizers that affect the movement of particles (granules), respectively: granule size, coefficient of granules friction, coefficient of granules restitution, aerodynamic resistance of granules, and particle strength.

The coefficient of granules friction, the aerodynamic resistance of granules, and the granules size, respectively granules size distribution are the most important properties because they greatly influences the pattern of granules spread [19]. Similar results regarding the physical properties of the fertilizers and the uniformity of their distribution were also reported in other studies [28], [37], [15], [1].

Fulton and Port (2016) [10] reported that physical properties: particle size (granules), particle density, bulk density, particle shape, crushing resistance, flow and friction coefficient are those that directly affect the mode of administration and the quality of spread (uniformity of distribution on field) of granulated fertilizers. It is considered that the particle size, followed by the particle density, is the major and impact factors that influence the uniformity of distribution and deposition of the granulated fertilizer [10].

Many studies have evaluated the granulometry of fertilizers in relation to the application equipment, for development of adequate equipment, and for facilities for adjusting and testing the equipment for the purpose of uniform application of fertilizers, with minimal errors [8], [6], [14]. In the same time, some studies have analyzed technical aspects of fertilizer applicators in relation to different types of fertilizers, dosages and application conditions [12, 13].

Studies and research on particle size and fertilizer granules have led to theoretical models describing the trajectory and distribution of fertilizer particles [3]. Jones et al. (2007) [22] compared different methods of testing the fertilizer distributor and the confidence in calculating and determining the working width on the fertilized crop, and Lawrance and Yule (2007) [24] studied the variation of fertilizer application in field conditions. The granulometry of the fertilizers was studied in relation to the static resistance of the fertilizers [25], in relation to humidity, method and fixed or variable application rate [9], [21].

Regarding to fertilizers and application equipment, there are quality standards, as well as codes and practical rules of application for the purpose of uniform fertilization and the economic efficiency of the fertilization work [20], [29].

In agricultural practice, numerous studies and researches have analyzed the application of fertilizers in relation to plant species and pedoclimatic conditions [26], [23], with the assortment of fertilizers [31, 32], with elements of productivity and quality of production [7], [33, 34], with costs and effects of the uneven application of fertilizers [27], with aspects of technical optimization and economic impact [4], [35], [13], [5], [36], or the relation of spectral bands with NDVI, as expression of plants nutrition status [17, 18].

The present study analyzed the physical properties of a sample of ammonium nitrate in terms of size and weight of particles by size classes.

MATERIALS AND METHODS

The study aimed to analyze the physical properties of the granules of a sample of ammonium nitrate. An analysis and classification of the granules was made according to their diameter by size classes.

For the study, samples of fertilizer were collected randomly from the bag. From the amount of fertilizer taken, four samples of fertilizer were analyzed, in volumes of 5 cm^3.

They were measured and determined: the diameter of the granules (D), the number of granules (GN) by size classes according to their diameter, the total weight of the granules on each size class (TWG), and the average weight of a granule (AWG) on each size class.

The diameter of the granules was measured with an electronic caliper with an accuracy of ±0.001mm. There were obtained 10 size classes according to diameter, in which the granules of the studied ammonium nitrate samples were framed.

The statistical analysis of the experimental data was performed with the mathematical and statistical analysis module from EXCEL, Office 2007, and with the PAST software [16]. For the data analysis, the ANOVA test, the statistical correlation analysis, the regression analysis were used, and as statistical safety parameters the correlation coefficients r and R^2, p, the sample F, the prediction error ε_i were used.

RESEARCH RESULTS

Dimensional analysis of granules on ammonium nitrate, with respect to diameter (D), number of granules (GN) by size classes, total weight of granules (TGW) on each size class, and average weight of a granule (AWG) from each size class led to the values are presented in table 1. Depending on diameter (D), the granules were classified into 10 size classes. The values of the granule diameter were between 3.48 ± 0.001 mm for class C1 and 1.19 ± 0.001 mm for class C10. The number of granules per size class ranged from 7 in the case of class C1 (3.48 ± 0.001 mm) to 65 in the case of class C10 (1.19 ± 0.001 mm), with a maximum of 157 granules in the case of size class C8 (1.90 ± 0.001 mm).

The total weight of the granules, by size classes, ranged between 0.171 ± 0.073 g in the C1 class and 0.193 ± 0.073 g in the C10 class, with the maximum value of 0.914 ± 0.073 in the C8 class. The average weight of a granule ranged from 0.00297 ± 0.0002 g in the case of class C10 to 0.02443 ± 0.0002 g in the case of class C1.

The single factor ANOVA test, for Alpha = 0.001, revealed the presence of the variance in the experimental data set as well as the statistical data safety, $p << 0.001$, F> Fcrit, table 2.

The statistical analysis regarding the distribution of the experimental data revealed a normal distribution of the experimental values for the four characteristics of the studied granules (D, GN, TWG and AWG).

Table 1.

Dimensional values of fertilizer granules on ammonium nitrate

Size Class	D (mm)	GN	TWG (g)	AWG (g)
C1	3.48	7	0.171	0.02443
C2	2.97	8	0.175	0.02188
C3	2.76	20	0.376	0.01880
C4	2.65	23	0.346	0.01504
C5	2.58	28	0.361	0.01289
C6	2.39	44	0.464	0.01055
C7	2.21	68	0.606	0.00891
C8	1.90	157	0.914	0.00582
C9	1.51	138	0.578	0.00419
C10	1.19	65	0.193	0.00297
SE	±0.001	-	±0.073	±0.0002

D – granule diameter (mm); GN – granule number; TWG – total weight of granules (g); AWG - average weight of granules (g)

Table 2.

ANOVA Single factor

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	22610.45	3	7536.818	10.77872	3.38E-05	6.743613
Within Groups	25172.32	36	699.2312			
Total	47782.78	39				

Alpha = 0.001

The analysis of correlation between physical parameters of the granules revealed the existence of very high positive correlations between AWG and D ($r = 0.961$) and high positive correlations between TGW and GN ($r = 0.830$). At the same time, negative correlations of moderate intensity were recorded between GN and D ($r = -0.744$), between AWG and GN ($r = -0.796$) as well as low negative correlations between AWG and TWG ($r = -0.574$), respectively between TGW and D ($r = -0.418$) were recorded. The values of the correlation coefficients are presented in table 3.

Table 3.

Matrix table of correlations between physical parameters on ammonium nitrate studied fertilizer

	D	GN	TWG	AWG
D		0.013646	0.22934	9.32E-06
GN	-0.744		0.002972	0.005862
TWG	-0.418	0.830		0.082965
AWG	0.961	-0.796	-0.574	

The distribution of granules by size classes, according to their diameter, was most accurately described by a smoothing spline model, for which error testing was calculated with relation (1), and parameters describing the equation are presented in table 4. The graphical distributions of the values for the number of granules according to the size class (D), as well as the graphic image of the smoothing spline model, are shown in figure 1.

$$\bar{\varepsilon} = \left(\sum_{i=1}^{n} \varepsilon_i \right) / n = \left(\sum_{i=1}^{n} \left| \frac{ys_i - y_i}{y_i} \right| \right) / n \qquad (1)$$

Table 4.

Spline - statistics of a given data point for describing the variation of GN values in relation to class size for ammonium nitrate

Size Class	x_i	GN			
		y_i	ys_i	ε_i	$I_{i/1}$
C1	3.48	7	6.462	0.0833	1.0000
C2	2.97	8	9.280	0.1379	1.6563
C3	2.76	20	17.294	0.1565	1.8794
C4	2.65	23	22.948	0.0023	0.0272
C5	2.58	28	27.454	0.0199	0.2389
C6	2.39	44	46.385	0.0514	0.6176
C7	2.21	68	78.054	0.1288	1.5471
C8	1.9	157	144.820	0.0841	1.0102
C9	1.51	138	136.650	0.0099	0.1187
C10	1.19	65	68.651	0.0532	0.6388
				ε_i = 0.0727	

The relationship of the interdependence between the average weight of a granule (AWG) and the diameter of the granules (D), by size classes, was most accurately described by a smoothing spline model, for which error testing was calculated with the relation (1), and parameters describing the equation are shown in table 5.

The graphical distribution of the values for the average of granule size (AWG) according to the diameter of the granules (D), by size classes, as well as the graphic image of the smoothing spline model, are shown in figure 2.

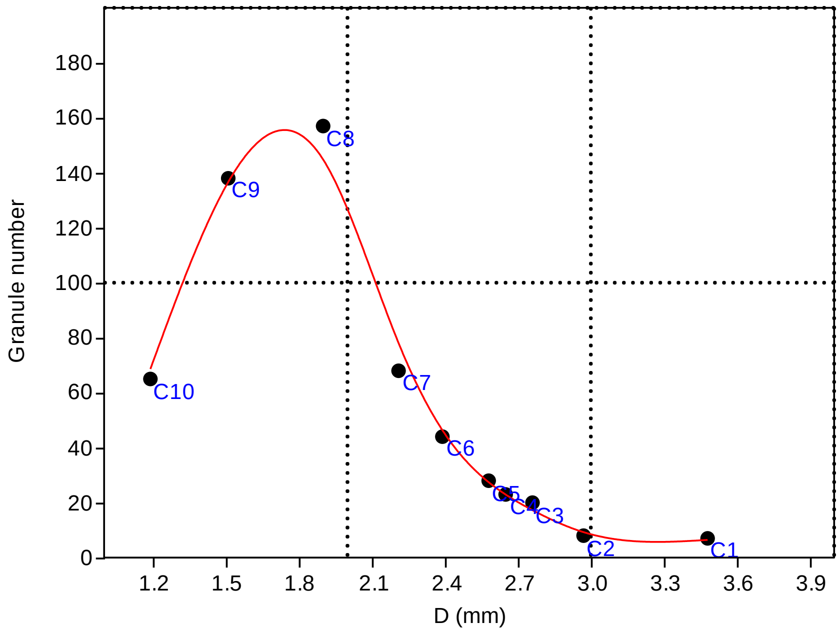

Figure 1. Distribution of granules by size classes according to diameter (D) and graphic image of smoothing spline model

Table 5.

Spline - statistics of given data point for describing the variation of AWG values in relation diameter of granules for ammonium nitrate

Size Class	x_i	AWG			
		y_i	ys_i	ε_i	$I_{i/1}$
C1	0.0244	0.0250	-0.0225	0.0225	1.0000
C2	0.0219	0.0207	0.0547	0.0547	2.4293
C3	0.0188	0.0174	0.0775	0.0775	3.4425
C4	0.0150	0.0154	-0.0250	0.0250	1.1106
C5	0.0129	0.0142	-0.0891	0.0891	3.9548
C6	0.0105	0.0111	-0.0474	0.0474	2.1053
C7	0.0089	0.0088	0.0168	0.0168	0.7455
C8	0.0058	0.0060	-0.0265	0.0265	1.1765
C9	0.0042	0.0040	0.0425	0.0425	1.8849
C10	0.0030	0.0029	0.0306	0.0306	1.3574
				ε_i = 0.0433	

Physical properties such as particle size and weight in granular fertilizers have been studied in relation to the uniformity of fertilizer application. For this purpose, different diagrams were developed regarding the size and structure by size classes of fertilizer granules. Also, studies were made on the trajectory of granules according to the applicator devices, the composition of the granules, and their shape and size [3], [10], [11], [12].

Allaire and Parent (2004) [2] reported the existence of relationships between certain physical properties of fertilizers and the possibility of using these relationships for partial estimation of other properties of fertilizers.

Antille et al. (2013) [3] reported that, in the case of the studied fertilizers, the classification of 80% of the granules in the range 2.25 - 4.40 mm, represented the optimum in relation to the uniform distribution of the granules on the soil.

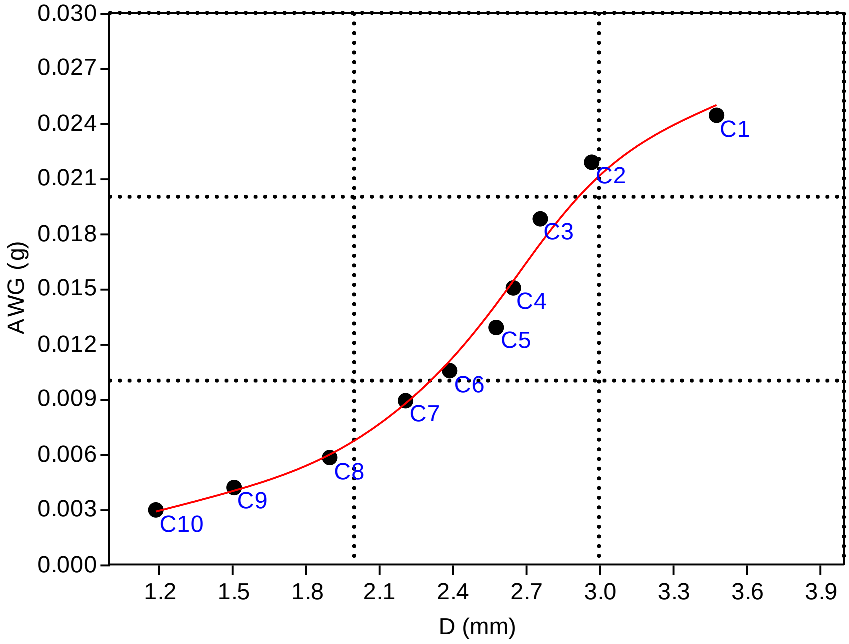

Figure 2. Graphical distribution of the average weight of the granules (AWG) according to the diameter of the granules (D) by size classes

Similarly, in the present study, based on the diameter (D) it was possible to accurately estimate the distribution of the granules by size classes and the average weight of a granule within each size class. Regarding the dimensional distribution of the granules, the studied fertilizer has a fine granulation, with percent of 64.52% granules with a diameter below 2 mm, percent of 34.23% granules with a diameter between 2.01 - 2.99 mm and, respectively, percent of 1.25% granules with diameter greater than 3.00 mm.

CONCLUSIONS

From the values of the dimensional distribution of the granules by size classes, the studied fertilizer, of ammonium nitrate type, is characterized by fine granulation, and between the studied properties correlations with high degree of confidence have been identified.

Based on the diameter of the granules (D), smoothing spline models made it possible to accurately, and in statistically safety conditions, estimate the physical properties of the fertilizer, such as the distribution of granules (GN) and the average weight of a granule (AWG) by size classes.

REFERENCES

[1]. APHALE A., BOLANDER N., PARK J., SHAW L., SVEC J., & WASSGREN C., 2003, Granular fertilizer particle dynamics on and off a spinner spreader. Biosystems Engineering, 85, 319-329

[2]. ALLAIRE S.E., & PARENT L.-E. 2004, Physical properties of granular organic-based fertilizers, Part 1: Static properties. Biosystems Engineering, 87, 79-87

[3]. ANTILLE D.L., GALLAR-REDONDO L., & GODWIN R.J., 2013, Determining the particle size range of organomineral fertilisers based on the spreading characteristics of the material. American Society of Agricultural and Biological Engineers (ASABE) meeting paper, pp. 18

[4]. BOLDEA M., & SALA F., 2010, Optimizing economic indicators in the case of using two types of state-subsidized chemical fertilizers for agricultural production. AIP Conference Proceedings, 1281(1), 1390-1393
[5]. BOLDEA M., SALA F., RAWASHDEH H., & LUCHIAN D., 2015, Evaluation of agricultural yield in relation to the doses of mineral fertilizers. Journal of Central European Agriculture, 16(2), 149-161
[6]. CAMACHO-TAMAYO J.H., BARBOSA A.M., PÉREZ N.M., LEIVA F.R., & RODRÍGUEZ G.A., 2009, Operational characteristics of four metering systems for agricultural fertilizers and amendments. Engenharia Agrícola, 29(4), 605-613
[7]. DOBREI A., SALA F., MĂLĂESCU M., & GHIȚ A., 2009, Researches concerning the influence of different fertilization systems on the quantity and quality of the production at some table grapes cultivars. Journal of Horticulture, Forestry and Biotechnology, 13, 454-457
[8]. FULTON J., & PORT K., 2016, Physical properties of granular fertilizer and impact on spreading. Ohio State University, FABE-550.1.
[9]. FULTON J.P., SHEARER S.A., STOMBAUGH T.S., ANDERSON M.E., BURKS T.F., & HIGGINS S.F. 2003, Simulation of fixed– and variable–rate application of granular materials. Transactions of the ASAE, 46(5), 1311-1321
[10]. FULTON J.P., SHEARER S.A., CHABRA G., & HIGGINS S.F., 2001, Performance assessment and model development of a variable–rate, spinner–disc fertilizer applicator. Transactions of the ASAE, 44(5), 1071-1081
[11]. GRAFTON M., YULE I., & MANNING M., 2017, A review of practices in precision application of granular fertilisers. 7th Asian-Australasian Conference on Precision Agriculture, pp. 6
[12]. GRAFTON M.C.E., IZQUIERDO D.A., YULE I.J., WILLIS, L.A., & MANNING M.J., 2015a., The effects of field conditions on in-field spread patterns from twin disk spreaders. ASABE, Paper No. 152189348 St. Joseph, Mich: ASABE
[13]. GRAFTON M.C.E., YULE I.J., ROBERTSON B.G., CHOK S.E., & MANNING M.J., 2015b., Ballistic modeling and pattern testing to prevent separation of New Zealand fertiliser products. Applied Engineering in Agriculture, 31(3), 405-413
[14]. GRAFTON M.C.E., YULE I.J., & MANNING M.J., 2013, A review of the economic impact of high levels of variance in fertiliser spreading systems. Proceedings of the New Zealand Grassland Association, 75, 139-144
[15]. GRIFT T.E., WALKER J.T., & HOFSTEE J.W., 1997, Aerodynamic properties of individual fertilizer particles. Transaction of the ASAE, St. Joseph, 40(1), 13-20
[16]. HAMMER Ø., HARPER D.A.T., & RYAN P.D., 2001, PAST: paleontological statistics software package for education and data analysis. Palaeontologia Electronica, 4(1), 1-9
[17]. HERBEI M.V., SALA F., & BOLDEA M., 2015, Relation of normalized difference vegetation index with some spectral bands of satellite images. AIP Conference Proceedings, 1648, 670003-1 - 670003-4
[18]. HERBEI M., & SALA F. 2016, Biomass prediction model in maize based on satellite images. AIP Conf. Proc., 1738:350009-1 – 350009-4
[19]. HOFSTEE J.W., & HUISMAN W., 1990, Handling and spreading of fertilizers part 1: Physical properties of fertilizer in relation to particle motion. Journal of Agricultural Engineering Research, 47, 213-234
[20]. ISO 5690, 1985, Equipment for distributing fertilizers- Test methods-Part1: Full width fertiliser distributors, ISO Standards Handbook, Agricultural Machinery, 13, International Organisation for Standardisation, 373-386
[21]. JI H.H., 2006, Moisture absorption of granular fertilizer and its distribution

characteristic by a pneumatic applicator. St. Joseph, ASABE. Paper No: 061072

[22]. JONES J.R., LAWRENCE H.G., & YULE I.J., 2007, A statistical comparison of international fertiliser spreader test methods – Confidence in bout width calculations. Powder Technology, 184, 337-351

[23]. KIDD J., MANNING P., SIMKIN J., & STOCKDALE E., 2017, Impacts of 120 years of fertilizer addition on a temperate grassland ecosystem. PLoS ONE, 12(3), e0174632

[24]. LAWRENCE H.G., & YULE I.J., 2007, Estimation of the in-field variation in fertiliser application, New Zealand Journal of Agriculture Research, 50, 25-32

[25]. MACÁK M., & KRIŠTOF K., 2016, The effect of granulometric structure and moisture of fertilizer on its static strength. Research in Agricultural Engineering, 62, S1-S7

[26]. MENGEL K., 1983, Responses of various crop species and cultivars to fertilizer application. Plant and Soil, 72(2-3), 305-319

[27]. MILLER P.C.H., AUDSLEY E., & RICHARDS I.R., 2009, Costs and effects of uneven spreading of nitrogen fertilisers. Proceedings of the International Fertiliser Society, 659, 1-24

[28]. MOHSENIN N.N., 1986, Physical properties of plant and animal materials: structure, physical characteristics, and mechanical properties. New York: Gordon and Breach, 1986. pp. 892

[29]. NEW ZEALAND FERTILISER QUALITY COUNCIL, 2013, New Spreadmark Codes of Practice. Wellington New Zealand: On line publication. Retrieved from: http://www.fertqual.co.nz**.**

[30]. ORTIZ-CAÑAVATE J., & HERNANZ J.L., 1989, Técnica de la mecanización agraria. 3rd ed. Madrid: Ediciones Mundi-Prensa, p. 642

[31]. RAWASHDEH H.M., & SALA F., 2013, The effect of foliar application of iron and boron on early growth parameters of wheat (*Triticum aestivum* L.). Research Journal of Agricultural Science, 45(1), 21-26

[32]. RAWASHDEH H.M., & SALA F., 2014**,** Foliar application of boron on some yield components and grain yield of wheat. Academic Research Journal of Agricultural Science and Research, 2(7), 97-101

[33]. RAWASHDEH H., & SALA F., 2015, Effect of some micronutrients on growth and yield of wheat and its leaves and grain content of iron and boron. BulletinUSAMV serie Agriculture, 72(2), 503-508

[34]. RAWASHDEH H., & SALA F., 2016, The effect of iron and boron foliar fertilization on yield and yield components of wheat. Romanian Agricultural Research, 33, 241-249

[35]. SALA F., BOLDEA M., RAWASHDEH H., & NEMET I., 2015, Mathematical model for determining the optimal doses of mineral fertilizers for wheat crops. Pakistan Journal of Agricultural Sciences, 52(3), 609-617

[36]. SALA F., & BOLDEA M., 2011, On the optimization of the doses of chemical fertilizers for crops. AIP Conference Proceedings, 1389, 1297-1300

[37]. WALKER, J.T., GRIFT, T.E., HOFSTEE, J.W., 1997, Determining effects of fertilizer particle shape on aerodynamic properties. Transaction of the ASAE, St. Joseph, 40(1), 21-27.