INVESTIGATION OF NATURAL MAGNESIUM MINERAL FERTILIZER GRANULATION AND DETERMINATION OF GRANULE QUALITATIVE INDICATORS

[1]Algirdas Jasinskas, [1]Juozas Pekarskas, [1]Vytautas Kucinskas, [2]Aivars Aboltins
[1]Aleksandras Stulginskis University, Lithuania; [2] Latvia University of Agriculture
algirdas.jasinskas@asu.lt

Abstract. Research was carried out in the Aleksandras Stulginskis University with the natural magnesium mineral fertilizers – sulphate monohydrate Kieserite that was granulated in China and magnesium silicate Serpentine rocks that were grounded and granulated with impact granulation technology in Lithuania. Serpentine fertilizer granules were sieved into two groups: larger-size and smaller-size Serpentine granular fertilizers which differed in their texture. Kieserite granular fertilizers prevailed from 3.1 to 4.0 mm and from 2.0 to 3.1 mm granular fraction; larger-size granules of Serpentine fertilizers were the same fraction as Kieserite granules, and the smaller-size granules of Serpentine fertilizer prevailed from 1.0 to 2.0 and from 2.0 to 3.1 mm granular fractions. Biometric and physical-mechanical properties of natural magnesium mineral Kieserite and Serpentine fertilizer granules were investigated, and their resistance to impact forces was evaluated. It was found that the maximum moisture content was in Kieserite granules – 9.3 %; and the moisture content of Serpentine fertilizer granules was about two times lower and ranged 4.8-4.9 %. The largest average density was of Kieserite granules – 2163.2 $kg \cdot m^{-3}{}_{DM}$ (dry matter), and the density of larger-size Serpentine granules was the lowest – 1255.9 $kg \cdot m^{-3}{}_{DM}$. The results on resistance to deformation of the investigated mineral fertilizers indicate that the granules made of Kieserite have the highest resistance; they decompose to 101.5 N force. The granules produced of Serpentine rock materials disintegrate to more than 10 times smaller external force: 8.7 N and 9.3 N. The research results show that the granules made of Kieserite are of the highest quality, these granules are greatly resistant to compression on a static force and they are convenient for transportation, storage and mechanical spreading.

Keywords: magnesium fertilizers, Kieserite, Serpentine, granules, properties, density, compression resistance.

Introduction

Minerals and rocks of natural origin are widely used to fertilize plants and improve the soil characteristics. Practically, all matters that are used for liming of soil are of natural origin. A significant part is also used in production of synthetic mineral fertilizers. In ecological agriculture, exceptionally mineral and organic matters of natural origin may be used [1; 2].

Minerals and rocks are chopped; if needed, they are processed, and lumber matters are removed from them. Usually, they are used for fertilization and improvement of the soil characteritics in dry form and, in rare cases, they are granulated. One of such fertilizers is granulated mineral Kieserite which is used in various agricultural systems as magnesium fertilizer [3-5]. Serpentine (magnesium hydrosylicate) ($Mg_6[Si_4O_{10}] \cdot [OH]_8$ or $3MgO \cdot 2SiO_2 \cdot 2H_2O$) is made of minerals antigorite, lizardite, calcite and chlorite; it is also rich in magnesium in which MgO may reach up to 40 % and more. This rock is attributed to the class of semiprecious stones. Till the present times, it has not been used in agriculture as fertilizer or for soil improvement. Apart from magnesium, Serpentine is also rich in other elements important in plant growth in agriculture [6-8]. More precise description of the nutrient proportion in the investigated fertilizers and their elemental composition are presented in papers [3; 8].

The aim of the research work is to investigate the natural magnesium mineral fertilizer granulation and to determine the qualitative indicators of the produced granules.

Materials and methods

New composition mineral granulated fertilizers were investigated:

1. *Granulated mineral Kieserite;*
2. *Larger-size Serpentine granular fertilizers;*
3. *Smaller-size Serpentine granular fertilizers.*

The following physical-mechanical characteristics of Serpentine and Kieserite mineral granulated fertilizers were investigated and determined: the moisture of granules; biometric parameters of granules: measurements, mass, density; filled density of granules and flow angles; strength of granules (resistance to pressure). This research has been performed using the standard methods and confirmed and used in methodologies of various institutions [9].

Moisture of granules. Moisture of granules is determined in chemical laboratories according to the standard methodology. For determination of moisture 3 samples 100 g each are taken. In the laboratory, relation of water in the sample with the sample mass is determined, i.e. moisture of granules is determined and the calculated average meaning of 3 samples is written down with the rror [9].

Biometrical parameters of granules. *Measurements and granulometric configuration of granules.* Kieserite was granulated in China and magnesium silicate Serpentine rocks were grounded and granulated in Lithuania with the impact granulation technology. The measurements of the produced granules were determined. The diameter of the granules is measured by sliding callipers (0.05 mm exactness) in the centre of the granules. Each test is repeated 5 times; average meanings of the granule mass and their errors are calculated.

Granule mass is determined by weighing with 0.001 g exactness. Average mass meanings of the measured 7 sort granules, 3 various size fractions are calculated, and they are written down with the error.

Density of granules. Knowing the determined measurements of the granules (diameters), their volume is calculated $V_{gr.}$; it is compared to the volume of a sphere:

$$V_{gr} = \frac{4}{3}\pi R^3 , \qquad (1)$$

where R – ray of sphere (granule), m.

While knowing the mass of a granule m_{gr} (exactness of weight indices is 0.01 g), the density of the granule mass ρ_{gr} is calculated:

$$\rho_{gr} = \frac{m_{gr}}{V_{gr}} , \qquad (2)$$

where ρ_{gr} – granule mass density kg·m^{-3}.

Knowing the moisture of the granules, the density of dry material (DM) of each sort of mineral fertilizers and data spread reliable interval (error) are calculated [9].

Granulometric configuration. Kieserite and Serpentine rocks granular granulometric (fractional) configuration was determined using a special sieve shaker "Haver EML Digital plus" and a set of 200 mm diameter sieves. The sieves with round holes are placed one on another (in the succession starting from the upper sieve): 7.1 mm; 5.60 mm, 5.00 mm; 4.00 mm; 3.15 mm; 2.00; 1.00 mm; 0.50 mm; 0.25 mm or less than 0.25 mm [10]. The granules of magnesium silicate Serpentine rocks were sieved into two groups: larger and smaller, and the measurements of these groups were fixed.

Granule filled density and flow angles. *Granule filled density* is determined by filling a cylindrical vessel of 1 dm^3 with granules (the vessel is weighted before filling it with the granules). The granules are filled till the upper edge in this vessel (freely, not pressing). Subtracting the mass of the empty vessel, we calculate the mass of the granules. Knowing the mass of the granules in a certain volume vessel, the density of thegranules is calculated (chopped straw mass (g) is divided by volume of a cylindrical vessel, m^{-3}). The test is performed three times. Also, the granule mass for dry materials is calculated.

Fall and natural slope angles are needed to project equipment for transportation of chopped straw to fire-places and depositories [11]. They are determined by a stand (Fig. 1).

A rectangular vessel is transparent, made of organic glass. The vessel is filled with 5 kg of granules; a damper is opened and it is allowed for the granules to fall naturally. Then, a ruler is turned and the angles are measured by a protractor:

- natural slope angle α_n;
- fall angle α_{gr} (of the chopped straw remaining in the vessel).

The test is repeated 3 times; average meanings and errors of the angles are calculated.

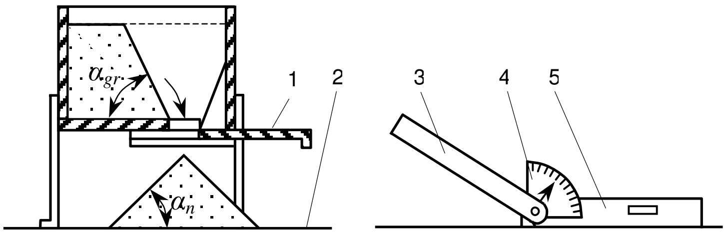

Fig. 1. **Scheme of determination equipment of natural slope and fall angles:** 1 – damper; 2 – horizontal surface; 3 – turning ruler; 4 – protractor; 5 – ruler with level

Granule resistance to compression. When analysing resistance to compression of the granules of mineral fertilizers, INSTRON testing equipment was used. The equipment is stored in the Aleksandras Stulginskis University, Institute of Agricultural Engineering and Safety (Fig. 2). During the tests, the granules were put on a horizontal surface (table), and the granules were affected by vertical load [12].

Fig. 2. **Research equipment of material characteristics *Instron 5960***

The results of the test were registered every 0.1 second till all granules dissociate under the force. INSTRON equipment draws Young's modulus characterising the granule resistance. Tests are repeated 5 times with every sort of granules. The measuring error is 0.02 %.

Having performed the experimental research, the received research data are processed by statistic-mathematical methods. During data processing, average meanings and their reliability intervals are calculated; the limit of the essential difference under 95 % of probability is evaluated.

Results and discussion

Determination of granule moisture. The research results of the moisture of granulated fertilizers show that the moisture of various sorts of granules (except for granulated Kieserite) differs insignificantly. The determined moisture of the granules is presented in Table 1. According to the obtained research data, it is possible to state that granulated Kieserite is the wettest – 9.29 ± 0.20 %; granulated Serpentine is almost two times less wet – 4.76-4.89 %.

Determination of biometrical parameters of granules. The analysed and determined biometrical parameters of granulated mineral fertilizer granules – the moisture content and density, are presented in Table 1.

As it is seen from the presented in the table biometrical characteristics of the granules of mineral fertilizers, the granules made of granulated Kieserite are of the highest density (2163.2 ± 582.7 DM).

The lowest density granules are obtained when pressing Serpentine to larger-size granules – 1255.9 ± 324.0 DM.

Table 1

Biometrical parameters of granulated mineral fertilizer granules

Species of granulated fertilizers	Moisture content, %	Bulk density, kg·m^{-3}
Granulated Kieserite	9.29 ± 0.20	2385.0 ± 642.4 2163.2 ± 582.7 DM
Larger-size Serpentine granular fertilizers	4.76 ± 0.36	1319.2 ± 340.2 1255.9 ± 324.0 DM
Smaller-size Serpentine granular fertilizers	4.89 ± 0.11	1509.2 ± 433.4 1435.2 ± 412.2 DM

The research results of granulometric (fractional) configuration of sulphate monohydrate Kieserite and magnesium silicate Serpentine granules show that Serpentine fertilizer granules, which were divided into two groups: larger-size and smaller-size, differed in their texture. Kieserite granular fertilizers prevailed from 3.1 to 4.0 mm and from 2.0 to 3.1 mm granular fraction. Larger-size granules of Serpentine fertilizers were the same fraction as Kieserite granules, and the smaller-size granules of Serpentine fertilizer prevailed from 1.0 to 2.0 and from 2.0 to 3.1 mm granular fractions.

Determination of filled density of granules and flow angles. The physical-mechanical characteristics of mineral fertilizers were determined: the filled density and natural slope and fall angles; the data are presented in Table 2.

Table 2

Physical-mechanical characteristics of granules of mineral fertilizers

Species of granulated fertilizers	Filled density, kg·m^{-3}	Natural slope angle, degrees	Fall angle, degrees
Granulated Kieserite	1219.7 ± 15.2 1106.4 ± 13.8 DM	29.0 ± 3.7	39.0 ± 3.7
Larger-size Serpentine granular fertilizers	1199.4 ± 93.3 1142.3 ± 88.8 DM	31.7 ± 2.8	32.7 ± 3.8
Smaller-size Serpentine granular fertilizers	1257.1 ± 91.1 1195.6 ± 86.6 DM	34.0 ± 4.9	38.3 ± 3.8

Note: $\overline{x}$ – arithmetical average meaning; $\overline{x}_{s\ m}$ – arithmetical average meaning of dry materials; $\Delta_{p,n-1}$ – interval of reliability of arithmetical average meaning.

As it may be seen from the data presented in Table 2, the filled density of three sorts of mineral fertilizers is rather high. It varies from 1106.4 till 1195.6 kg·m$^{-3}_{DM}$.

The determined natural slope dryness angles α_n vary from 29.0 till 34.0 degrees. The fall angle α_n meanings are close to those of the natural slope angles; they vary from 32.7 till 39.7 degrees.

Research in granule resistance to compression. Resistance to compression is an important parameter for granules of mineral fertilizers. It is very important for transportation and storage of granules. Having performed research in resistance to compression of three sorts of granules of mineral fertilizers, we received the results that are presented in Fig. 3-5.

During the tests, the beginning of deformation of the granules of mineral fertilizers (characteristic to that sort) and the force under which a granule is disintegrated were determined.

Analysing the deformation curve (Fig. 3) of the granulated Kieserite granules (No 1), it may be seen that a granule started deformation under the force of 10 N, and under the force of 101.5 N it disintegrated totally. Having evaluated the force and its change and the moisture of the granules (9.3 %), it may be stated that these granules are very resistant to static force, and it is comfortable to transport and to mechanically spread them.

Analysing the deformation curve (Fig. 4) of larger-size granules of granulated Serpentine (No 2), it may be seen that the granules started to deform quickly under the force of 0.9 N, and under the force of 9.2 N they deformed, but did not disintegrate fully. Having repeatedly reached the force of 7.7 N, they disintegrated in full. Having evaluated the force and its change and low moisture of granules (4.8 %), it may be stated that these granules are not sufficiently resistant to static force, and they disintegrate rather quickly.

Similarly to bigger granules of granulated Serpentine (No 2), we received the deformation curve (Fig. 5) of smaller granules of granulated Serpentine (No 3). It may be seen that a granule started to deform under the force of 1.0 N, and under the force of 8.7 N it deformed and disintegrated. Having evaluated the force and its change and low moisture of the granules (4.9 %), it may be stated that these granules are also not sufficiently resistant to static force and disintegrate quickly.

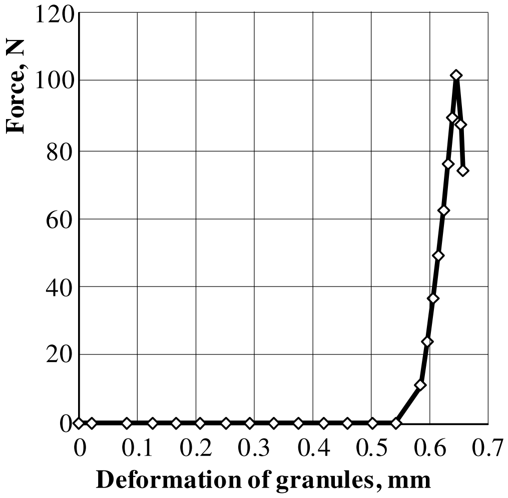

Fig. 3. **Deformation (mm) and disintegration force (N) of granulated Kieserite granules**

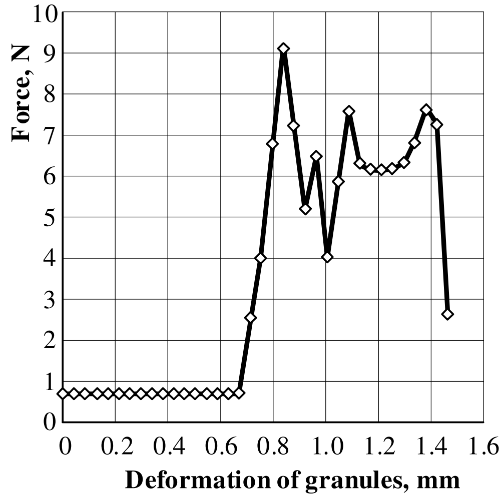

Fig. 4. **Deformation (mm) and disintegration force (N) of granulated Serpentine larger-size granules**

The obtained research results show that the granules made of Kieserite mineral fertilizers are most resistant to operating forces (101.5 N force is needed for their disintegration). The investigated larger-size and smaller-size Serpentine granular fertilizers are more than 10 times less resistant to operating forces (disintegration force 8.7-9.2 N). But all these granules are sufficiently resistant to operating load, and they may be transported and spread mechanically comfortably.

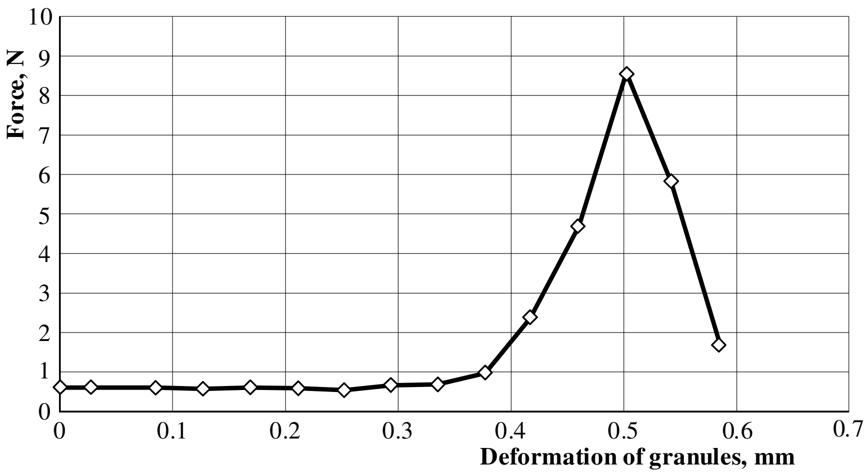

Fig. 5. **Deformation (mm) and disintegration force (N) of granulated Serpentine smaller-size granules**

Conclusions

1. Having analysed the moisture of the produced mineral fertilizers, it has been determined that granulated Kieserite is the wettest – 9.29 ± 0.20 %; granulated Serpentine is almost two times less wet – 4.76-4.89 %.
2. The granules made of granulated Kieserite are of the highest density – 2163.2 ± 642.4 $kg \cdot m^{-3}{}_{DM}$ (dry matter). Granules of the lowest density are received by pressing Serpentine to larger-size granules – 1255.9 ± 340.2 $kg \cdot m^{-3}{}_{DM}$.
3. It has been determined that the filled density of the analysed granules of three sorts of mineral fertilizers is rather high, and it varies from 1106.4 till 1195.6 $kg \cdot m^{-3}{}_{DM}$. Having analysed the flow angles, it has been determined that the flow angles of natural slope vary from 29.0 till 34.0 degrees. The fall angle meanings are close to those of the natural slope angles; they vary from 32.7 till 39.7 degrees.
4. It has been determined that the granules made of Kieserite mineral fertilizers are most resistant to operating forces (101.5 N force is needed for their disintegration). The investigated larger-size and smaller-size Serpentine granulated fertilizers are more than 10 times less resistant to operating forces, but all these granules are sufficiently resistant to operating load, and they may be transported and spread mechanically comfortably.

References

1. Čiuberkis S., Čiuberkienė D., Končius D., Lapinskas E., Ambrazaitienė D., Piaulokaitė-Motuzienė L. Effect of liming and fertilizing systems on soil properties and productivity of agrocenoses. Žemės ūkio mokslai, Nr. 2, 2005, pp. 1-12 (in Lithuanian with English summary and abtract).
2. Ožeraitienė D., Plesevičienė A.K., Vytautas Gipiškis V. Duration of action of different lime fertilizers and their effect on soil properties and yield of crop rotation crops. Žemdirbystė. Mokslo darbai, vol. 1 (93), 2006, pp. 3-21 (in Lithuanian with English summary and abtract).
3. Heming S.D., J.F. Hollis J.F. Magnesium availability from kieserite and calcined magnesite on five soils of different pH. Soil Use and Management, vol.11 (3), 1995, pp. 105-109.
4. Jamieson C.S, Noe Dobrea E. Z., Dalton III J. B., Pitman K. M., Abbey W. J. The spectral variability of kieserite ($MgSO_4 \cdot H_2O$) with temperature and grain size and its application to the Martian surface. Journal of Geophysical Research: Planets, vol. 119 (6), 2014, pp. 1248-1237.
5. Artus M., Kostiv I. Conversion of Langbeinite and Kieserite in Schoenite With Mirabilite and Sylvite in Water and Schoenite Solution. Journal of Chemical Engineering & Process Technology, vol, 6 (225), 2015, pp.1-3.
6. Andreani M., Grauby O., Baronnet A., Muñoz M. Occurrence, composition and growth of polyhedral serpentine. European Journal of Mineralogy, vol. 20, 2008, pp.159–171.
7. Boudier F., Baronnet A. and Mainprice D. Serpentine Mineral Replacements of Natural Olivine and their Seismic Implications: Oceanic Lizardite versus Subduction-Related Antigorite. Journal of Petrology, vol. 51(1-2), 2010, pp. 45-512.
8. Deschamps F., Guillot S., Godard M., Andreani M.,Hattori K. Serpentinites act as sponges for fluid-mobile elements in abyssal and subduction zone environments. Terra Nova, vol. 23 (3), 2011, pp.171-178.
9. Jasinskas A. The evaluation of physical-mechanical properties of willow stems and their chaff. Žemės ūkio inžinerija: LŽŪII ir LŽŪU mokslo darbai, 2007, t. 39(2), p. 81-91 (in Lithuanian).
10. Šiaudinis G., Jasinskas A., Šarauskis E., Steponavičius D., Karčiauskienė D., Liaudanskienė I. The assessment of Virginia mallow (Sida hermaphrodita Rusby) and cup plant (Silphium perfoliatum L.) productivity, physicomechanical properties and energy expenses // Energy. 2015. vol. 93, part 1, pp. 606-612.
11. Sirvydis J., Dravininkas A. The basics of artificially dried grass forage technology. LŽŪU Žemės ūkio inžinerijos institutas. 2005. 229 p. (in Lithuanian).
12. Jasinskas A., Steponavičius D., Šarauskis E., Šniauka P., Vaiciukevičius E., Zinkevičius R. Laboratory works of agricultural machinery [Electronic resource] / Lietuvos žemės ūkio universitetas. Žemės ūkio inžinerijos fakultetas. Žemės ūkio mašinų katedra. Akademija, 2010. 110 p. (in Lithuanian).