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EFFECTS OF THE APLICATION SYSTEM ON THE PHYSICAL AND MECHANICAL PROPERTIES OF MINERAL FERTILIZERS

UTICAJ TEHNOLOŠKO-TEHNIČKOG SISTEMA APLIKACIJE MINERALNIH ĐUBRIVA NA NJIHOVE FIZIČKO-MEHANIČKE OSOBINE

Marija GAVRILOVIĆ[*], Aleksandra DIMITRIJEVIĆ[*], Milivoj RADOJIČIN[**], Zoran MILEUSNIĆ[*], Rajko MIODRAGOVIĆ[*]
[*]*University of Belgrade, Faculty of Agriculture, Beograd, Nemanjina 6*
[**]*University of Novi Sad, Faculty of Agriculture, Novi Sad, Trg Dositeja Obradovića 8*
e-mail: saskad@agrif.bg.ac.rs

ABSTRACT

Mineral fertilizers have a pivotal role in contemporary agricultural production, especially when seeking to exploit the full biological potential of crops. This paper presents the results of a three-year experiment on the distribution uniformity of different mineral fertilizer application systems. One of the objectives in this study was to define the physical and mechanical properties of four different types of mineral fertilizers and examine their changes during storage, transportation and application. A total of four fertilizers were taken into account: UREA, CAN, MAP and NP. The main physical properties, i.e. particle size, particle size distribution, friction coefficient, angle of repose and particle resistance, were analyzed on samples collected from the storage, the trailer (prior to application) and the field (after application). The results obtained show that fertilizers with a particle size distribution of 3.3 to 4.75 mm exhibit higher values of the angle of repose, friction and resistance. The lowest value of the angle of friction (17.53 ^{0}) was observed in the UREA fertilizer after application, whereas the highest angle of friction (24.37 ^{0}) was measured in the MAP fertilizer obtained from the storage. The values of the static repose angle varied depending on the fertilizer type and the place of sampling (storage, trailer or field). The lowest value of the static repose angle (30.34 ^{0}) was measured in the MAP fertilizer after application, whereas the highest static repose angle (36.91 ^{0}) was measured in the NP fertilizer from the storage. The NP fertilizer exhibited the highest value of the dynamic friction angle, whereas the lowest value of the dynamic friction angle was calculated for the UREA fertilizer. The NP fertilizer particles showed the highest resistance, whereas the UREA fertilizer particles were most susceptible to breakage.

Keywords: *mineral fertilizers, physical properties, storage, centrifugal spreaders*

REZIME

Savremena poljoprivredna proizvodnja se ne može zamisliti bez primene đubriva, posebno sa aspekta boljeg korišćenja biološkog potencijala rodnosti gajenih biljaka. U radu je prikazan deo rezultata trogodišnjih ispitivanja tehničko-tehnološkog sistema aplikacije mineralnih đubriva različitim tipovima centrifugalnih rasipača. Jedan od ciljeva istraživanja bio je i određivanje fizičko–mehaničkih osobina različitih tipova mineralnih đubriva, njihovih promena tokom samog procesa aplikacije i njihovog uticaja na kvalitet same aplikacije. U istraživanje su uključena četiri tipa mineralnih đubriva i to UREA, KAN, MAP i NP.

Dobijeni rezultati tokom ispitivanja fizičko–mehaničkih osobina primenjivanih mineralnih đubriva pokazuju da đubriva koja imaju najveći procenat granula prečnika između 3,3 mm i 4,75 mm imaju najveće uglove trenja i nasipanja, kao i dobru otpornost prema lomu granule. Vrednosti ugla trenja su značajno varirale u zavisnosti od tipa đubriva i mesta uzorkovanja. Najniža vrednost, 17,53^o je zabeležena kod UREE nakon aplikacije a najviša, 24,37^o kod đubriva MAP iz skladišta na imanju. Vrednosti statičkog ugla nasipanja su takođe statistički značajno varirale u zavisnosti od tipa đubriva i mesta uzorkovanja. Najniža vrednost, 30,34^o, je zabeležena kod đubriva MAP nakon aplikacije a najviša, 36,91^o, je zabeležena kod NP đubirva iz skladišta. NP đubrivo je pokazalo i najviše vrednosti dinamičkog ulga trenja. Najniže vrednosti ovog parametra, 23,35^o, imalo je đubrivo UREA. Čvrstoća granula je varirala u zavisnosti od tipa đubriva i od mesta uzorkovanja. Najviše vrednosti su zabeležene kod đubriva NP u svim fazama manipulacije dok su najniže vrednosti zabeležene kod đubriva UREA.

Ključne reči: *mineralna đubriva, fizičke osobine, skladište, centrifugalni rasipači.*

INTRODUCTION

Mineral fertilizer application is aimed at providing an adequate amount of nutrients to cultivated crops (Villette et al., 2017). In order to provide an optimal utilization of nutrients, each part of the field must receive the same fertilizer quantity (Tissot et al, 2002).

The application quality of a dry granular fertilizer and the spreading uniformity depend on several variables. On balance, the performance of a fertilizer applicator can be contributed to 1/3 operator, 1/3 applicator and 1/3 fertilizer characteristics. Physical properties of a fertilizer affect the distribution pattern and are of crucial importance to farmers, fertilizer manufactures, fertilizer distributors and drills (Turgut et al, 1994, Marquering and Scheufler, 2002). It is important to understand the physical properties of fertilizers as they influence the ballistic nature, aerodynamic properties and particle trajectories of different fertilizers (Fulton and Port, 2016, Hula et al., 2017). The most important physical properties of the granulated fertilizers are particle size, particle size distribution, bulk density, friction coefficient, angle of repose and the particle resistance to crushing.

Particle size has an exponential impact on the fertilizer spread width and the risk of product segregation. In general, larger particles are thrown further by a spreader than smaller ones. Therefore, a wider spread width can be used for larger particles (Fulton and Port, 2016, Goss et al, 2010). Conversely, greater variations in particle size within a fertilizer will lead to higher risks of uneven distribution and/or segregation. This is especially true in the case of fertilizer blends.

Floden (1994) argues that friction properties are of great importance to storing, transportation and distribution of granular materials. Friction phenomena can be divided into two categories: internal and external friction. Moreover, each category itself can be further divided into static and dynamic friction. Accordingly, this indicates why friction properties have to be taken into consideration in almost every phase of handling. Prilled fertilizers feature lower internal friction and a lower angle of repose than granulated (Fulton 1994). Coating of granules results in decreased internal friction and decreased external friction in most cases.

The angle of repose is the angle that the sloping surface of a heap of loose material poured on a horizontal surface makes with the horizontal surface. The International Standardization Organization (ISO 8398, 1989) defines it as the angle at the base of a cone of fertilizer formed with the vertical axis, as the material is allowed to fall onto a horizontal base plate under specified conditions. The particle shape, size and surface texture of a fertilizer influence its angle of repose. The knowledge of the angle of repose is necessary for designing fertilizer hoppers, chutes and conveyors, as well as the sloped roofs of fertilizer bulk storage buildings.

Particle resistance to breakage (crushing strength) is a very important physical property that defines handling and storage features of a granular material and determines the pressure limits applied during the bag and bulk storage of granular fertilizers. Hardness directly influences the spread width and operating disc speed. Harder products can be spread wider and used with high spinner disc speeds (> 800 rpm). Soft fertilizers need to be spread at slower disc speeds resulting in lesser spread widths. Soft products should be spread at disc speeds below 800 rpm, and the specific speed is determined as the maximum disc speed at which no particle fracturing or shattering is observed (Fulton and Port, 2016). Macak and Kristof (2016) pointed out that there are differences in static strength between prilled and granular fertilizers and that there is a need for more caution during the handling, storage and application of prilled fertilizers, the quality of which may be affected (at some point) by greater static loads.

This paper presents the results of a three-year experiment on fertilizer application systems. A part of the study also deals with the physical properties of four different granulated fertilizer types and their behavior during storage, transportation, handling and field application.

MATERIAL AND METHOD

The mechanical properties of four different types of mineral fertilizers and their changes during storage, transportation and field application were analyzed in this paper. The granulated UREA (Carbamide) fertilizer contains 46 % of nitrogen and 1.2 % of biuret, and is 100 % soluble in water. The UREA fertilizer particles are white in color and odorless, featuring a bulk density of 0.7-0.78 g/cm³. The calcium ammonium nitrate (CAN) fertilizer contains 27 % of nitrogen. The CAN fertilizer particles are yellowish-white and odorless, featuring a bulk density of 0.9-1 g/cm³. The monoammonium phosphate (MAP) fertilizer contains 11 % of nitrogen and 52 % of phosphorus. The MAP fertilizer particles are light brown and odorless, featuring a bulk density of 0.9-1.1 g/cm³. The mixed NP fertilizer contains 20 % of nitrogen and 20 % of phosphorus. The NP fertilizer particles are light gray and odorless, featuring a bulk density of 0.9 - 1.1 g/cm³.

The testing of the mechanical properties of the fertilizers analyzed was carried out at the Laboratory for Biosystems Engineering, the Faculty of Agriculture, the University of Novi Sad, and at the Laboratory of the Department of Agricultural Engineering, the Faculty of Agriculture, the University of Belgrade. Main physical properties such as particle size, particle size distribution, friction coefficient, angle of repose and particle resistance were analyzed on samples taken from the storage, the hopper trailer (prior to application) and the field (after application). The following measuring equipment was used: the precision scale Kern 572-33 Version 5.8, 04/ 2010 (Mechanikus Gottlieb KERN, Germany) (with a precision of d = 0.01 g), the Vicon Greenland Art.nr. 797770150 (Kverneland group, UK) sieves with sieve openings of 2 mm, 3.3 mm and 4.75 mm, the TMS PRO texture measurement system (Food Technology Corporation, USA), and a laboratory set for determining the friction coefficient and the angle of repose (static and dynamic).

The analysis of variance was used for statistical analyses. The testing of differences in the average mean values obtained was performed using the Tukey test (at significance levels of 0.05 and 0.01) and the Microsoft Office Excel 2007 software.

RESULTS AND DISCUSSION

Particle size distribution is an important factor affecting the angle of repose and the volumetric mass. Fertilizers with a wide range of particle sizes, including very small particles, are difficult to spread uniformly. Provided a blended fertilizer is used, the particle diameters of different products should be within 10 % of each other in order to avoid segregation. The particle size of fertilizers is influenced by many factors including transportation, conveyance, handling and metering. These processes can reduce the size of some particles, which can increase the particle size variability within a load. (Fulton and Port, 2016).

Table 1 shows the particle size distribution in the storage before and after application. There are significant statistical differences in the share of same fractions within different fertilizers taken from the same place (storage, trailer and field). The fertilizer type dictates how the fertilizer will “behave” during, storage, transportation and application. As can be seen in Table 1, the share of particles smaller than 2 mm in diameter tends to increase during fertilizer field application. This is the case with all the fertilizers analyzed. The results obtained show that the UREA fertilizer claimed the largest share (84.72 %) of the particles with a diameter of 2-3.3 mm (as measured in the sample taken after storage). The CAN fertilizer claimed the highest share (53.83 %) of the particles with a diameter of 3.3-4.75 mm (as measured in the sample taken after storage). The same was observed in the NP (62.31 %) and MAP fertilizers (71.32 %).

When samples were collected after the transport of fertilizers to the field, the particles with a diameter of 2-3.3 mm claimed the largest share (80.81 %) in the UREA fertilizer, whereas the particles with a diameter of 3.3-4.75 mm claimed the largest share (47.19 %) in the CAN fertilizer. In like fashion, these particles claimed a share of 61.15 % in the NP fertilizer and a share of 70.62 % in the MAP fertilizer. The dominant particle size in the UREA fertilizer after application was that of 2-3.3 mm (79.31%). As for the other fertilizer, the largest share was claimed by the particles with a diameter of 3.3-4.75 mm (CAN – 43 %, NP - 53.07 % and MAP – 69.80 %).

The static angle of friction defines how far the fertilizer particle will fly before setting down on the ground.

Table 1. Particle size distribution (%)

Fertilizer	Particle size (mm)	Storage	Hopper trailer	Filed	Tendency
UREA	r < 2	2.84	6.68	9.38	↑
	r > 2	84.72	80.87	79.31	↓
	r > 3.3	12.44	12.45	11.31	↑
CAN	r < 2	7.53	15.55	21.47	↑
	r > 2	23.43	22.31	21.98	↓
	r > 3.3	53.83	47.20	43.00	↓
	r > 4.75	15.21	14.96	13.61	↓
NP	r < 2	1.69	2.02	3.17	↑
	r > 2	28.18	28.53	34.96	↑
	r > 3.3	62.31	61.6	53.07	↓
	r > 4.75	7.82	7.95	8.68	↑
MAP	r < 2	1.60	7.47	29.16	↑
	r > 2	12.91	7.37	7.07	↓
	r > 3.3	71.32	70.62	69.80	↓
	r > 4.75	14.18	14.54	13.41	↓

The coefficient of friction is also used to incorporate side effects resulting from mutual interactions of particles, i.e. suction by the vanes, rolling of particles, and etc. (Dobler and Flatow, 1968). Under such conditions, the coefficient of friction is an apparent coefficient of friction. An increase in the coefficient of friction results in an increase in the residence time and a decrease in the velocity along the vane. A lower velocity along the vane further results in a decrease in the radial velocity, the discharge velocity and consequently the discharge angle. The magnitude depends on such variables as the pitch angle, rotational velocity and feed radius. Table 2 presents the values of fertilizer particle friction coefficients.

Table 2. Friction coefficient

Fertilizer	Storage	Hopper trailer	Filed
UREA	18.73	18.10	17.53
CAN	22.17	21.77	21.83
NP	23.00	22.80	23.00
MAP	24.37	23.70	23.07

The results obtained show that the MAP fertilizer exhibits the highest friction coefficient, whereas the UREA fertilizer has the lowest value of the parameter. All four fertilizer types are susceptible to changes in the friction coefficient during storage, transportation and application. The statistical analysis performed shows that the CAN and NP friction coefficients are less sensitive to handling operations than the UREA and MAP friction coefficients.

The static and dynamic angle of repose is the most important factors defining the fertilizer storage technology and technical systems (Turan et al., 2010). The dynamic angle of repose has a more practical significance as bulk materials are in constant movement. The values of the angle of repose for fertilizers normally range from about 25 ° to 40 °. Spherical products like prilled urea feature a low angle of repose (< 30 °), wheeras irregularly shaped products such as the granular KCl have a high angle of repose (> 35 °). Larger materials have higher angle of repose values than fine materials. In most rocks and sands, the angle of repose is 30 ° to 35 ° (Rutland et Polo, 2005). Table 3 shows the average values of these two parameters for all the experimental fertilizers during storage, before and after application.

The results obtained show that these two parameters were also varying during storage, transportation and fertilizer application.

Table 3. Static and dynamic angle of repose, °

Fertilizer	Storage		Hopper trailer		Filed	
	Static	Dyn.	Static	Dyn.	Static	Dyn.
UREA	32.48	23.35	32.07	23.35	32.38	23.45
CAN	34.71	32.46	33.69	31.80	33.73	31.68
NP	36.91	36.13	35.95	35.24	36.16	35.04
MAP	31.76	29.19	30.62	28.65	30.34	28.72

The dynamic angle of repose was lower in the UREA fertilizer, indicating a more spherical shape of the UREA fertilizer (as expected). The highest value was observed in the NP fertilizer, which remained invariant during storage, transportation and fertilizer application.

Particle strength (particle resistance) has an indirect effect on the particle motion (Hofstee and Huisman, W. (1990). Particles that do not have sufficient strength will break during motion in the fertilizer distributor. This results in changes in the particle size distribution which in turn influence the particle motion. Table 4 shows the particle resistance after storage, transport and filed application. The parameter values obtained are varying and tend to decrease at the end of the application process.

Table 4. Particle resistance (average force needed for particle breakage), N

Fertilizer	Storage	Hopper trailer	Filed
UREA	6.22	6.23	6.21
CAN	24.71	19.54	21.11
NP	54.62	68.08	47.71
MAP	21.18	22.40	20.09

The results obtained show that the average force needed for the UREA fertilizer particle breakage was 6.22 N, leading to a deformation of 0.07 mm. A significantly greater force was needed for breaking the CAN fertilizer particle taken from the storage (24.71 N). This force led to a significantly higher deformation of 0.97 mm. Similar results were observed in the MAP fertilizer with the forces needed for particle breakage varied from 20.09 to 22.40 N, causing particle deformations of 0.20 to 0.24 mm. The NP fertilizer was the least sensitive to cracking. The force needed for particle breakage varied from 47.71 to 68.08 N, causing deformations of 0.52 to 0.62 mm. The statistical analysis performed showed that there is a significant difference in the particle breaking force between all four fertilizers and all three processed (namely storage, transport and application). The CAN and MAP fertilizers do not differ significantly. The results obtained show that the NP fertilizer is the most resistant to the breaking force. However, the UREA fertilizer was found to be very soft and susceptible to destruction, requiring lower disk speed when a disk spreader is used. The results obtained also indicate that different storage technologies must be used for the UREA and NP fertilizers.

CONCLUSION

The results obtained show that scrupulous attention should be paid to the physical and mechanical properties of solid chemical fertilizers as they influence the application uniformity and the overall quality of application. It can be argued that these properties vary during storage, transportation and field application. Therefore, the issue of minimizing such changes needs to be tackled before field application in order to prevent uneven distribution, high drift losses, etc.

All the fertilizers tested indicate an increase in the share of smaller particles during storage, transportation and application, whereas the UREA is the most susceptible to breakage. Slight changes in the angle of repose were recorded in the NP fertilizer, as well as in the NP fertilizer values of resistance to breakage. On the basis of the results obtained, it can be concluded that the NP fertilizer is most suitable for storage, transportation and handling operations, whereas the UREA fertilizer can only bear careful handling.

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