DEVELOPMENT OF METHOD AND STUDY OF GRANULAR FERTILIZER PRODUCTION PROCESS BASED ON SAPROPEL

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Abstract. Considering the prospects of using organic sapropel as a raw material for fertilizers in agriculture, particularly in organic farming, its processing becomes an extremely important step. Traditional organic fertilizers, such as manure, are produced virtually untreated using a fairly simple technology, and their quantity is limited by the number of animals. The quality of sapropel-based fertilizers depends on the content of the organic part, the processing method, and the characteristics of the deposit. An analysis of the existing research has shown that sapropel-based fertilizers can be single-component and multi-component. In addition, the content of organic matter in such fertilizers varies widely. Many studies have been devoted to the production of granular sapropel fertilizers and the processes of forming and drying independent particles of arbitrary size and shape, the formation of large balls and strands by pressing, the formation of particles in the form of plates, cylinders, etc. But, given the design features of bulk fertilizer machines, it is necessary to strive for the formation of granules in the form of a ball. The paper proposes directions for the use of sapropel in the production of single-component and multicomponent granular fertilizers. The design of machines for the production of granular sapropel fertilizers in the form of balls with an equivalent diameter of 2-6 mm is presented. The results of experimental studies on the strength, fractional composition, volume, and unit density of granules produced in laboratory conditions are also presented. The obtained results demonstrate the feasibility of implementing the development in production conditions and suggest directions for improvement.

Keywords: granular fertilizer, sapropel, mixture, strength.

Introduction

Soils that are systematically cultivated and continuously used for crops eventually become depleted, losing their own accumulated humus reserves and degrading rapidly [1-3]. The degradation of soils is accelerated due to intensive farming practices and the use of mineral fertilizers and plant protection products. Although the algorithm for applying mineral fertilizers to the soil is based on an analysis of the content of macro-elements, farmers often do not adhere to these norms and may exceed them several times in order to achieve profitable yields [1].

Consequently, organic fertilizers have a regenerative effect on the soil, minimizing harmful effects and stabilizing, and in some cases, increasing humus content [2; 3]. Given the significant reduction in the availability of manure in Ukraine, fertilizers formed on the basis of long-term natural organic sapropel deposits have particular prospects. According to expert estimates [4; 5], the reserves of organic sapropels found in Ukrainian deposits could sustain their industrial processing for decades.

The main composition of such fertilizers can be supplemented with local mineral components such as potassium salt, phosphorites, sulfur, apatites, and others. For instance, potassium salt can be obtained from deposits in the Dnieper-Donets Basin and the Transcarpathian Foredeep with a total reserve of 4.3 billion tons; sulfur in the deposits of the Carpathians – 0.4 million tons; phosphorites within the Volyn-Podillya Plate, Crimea, Transcarpathia, and in some regions of the Dnieper-Donets Basin – 0.5 million tons; apatite-bearing ores in Torchin, Novopoltavsk, Stremigorodsk, and Fedorivsk – 3.3 billion tons [6]. To provide nitrogen nutrition, chicken manure can be included in the composition of fertilizers.

At the same time, the effectiveness of sapropel-based fertilizers can be ensured through proper processing of the raw material. Granulated forms of sapropel fertilizers provide the highest technological efficiency for application [7; 8]. In this regard, for application by existing machinery and to meet the quality requirements of the working process, the granule should have a spherical shape and maintain its strength during interaction with the working elements of these machines.

The incorporation of local mineral nutrients into granulated fertilizers made from sapropel raw materials will enhance their effectiveness. The organic component will promote the development of microflora, the formation of a favorable soil structure, and the improvement of the soil water-air regime [4; 5]. Meanwhile, the added mineral components will provide mineral nutrition to plants.

Analysis of technical solutions in the field of material granulation indicates that there are various machine designs that can be used for the production of sapropel granulated fertilizers [9-14]. However, most of them have certain drawbacks that hinder their use for producing granules that meet the aforementioned requirements.

Based on the synthesis of identified advantages and disadvantages, a machine design (Fig. 1) has been proposed, which combines the method of extrusion of plastic mass with its contact drying and convective ventilation in a drum dryer [8].

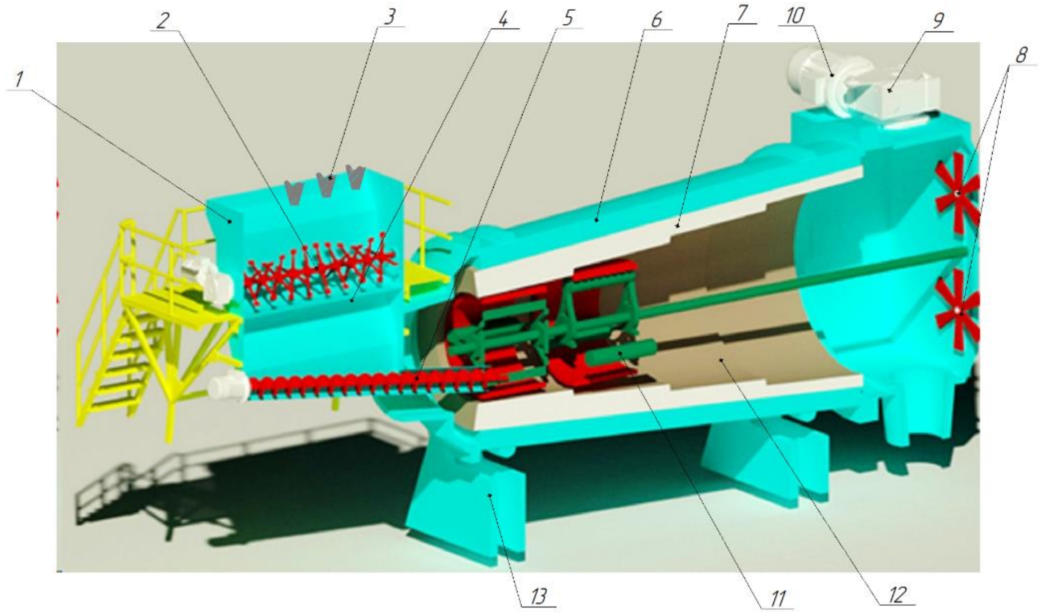

Fig. 1. **3D model of a machine for production of organic sapropel-based fertilizers:** 1 – hopper; 2 – mixers; 3 – dispensers; 4 – valve; 5 – screw conveyor; 6 – drum; 7 – drying surface with ceramic coating; 8 – fans; 9 – reducer; 10 – electric motor; 11 – rollers; 12 – perforated cylinder; 13 – supports

The objective of our investigation was to evaluate the applicability of the proposed method for sapropel-based granule production by assessing the dimensions, density, and strength characteristics of the resulting granules.

Materials and methods

To implement the working process, the sapropelic raw material enters the upper part of the two-section receiving hopper (1) of the mixing device. The necessary amount of the powdered mineral component is fed there through dispensers (3). With the help of mixers (2), the components are mixed to the required uniformity. The prepared mixture reaches the lower part of the hopper after opening the valve (4), from where it enters the inner part of the drum (6) with the help of a screw conveyor (5). Then, the rollers (11) extrude the viscous organo-mineral mixture through the holes of the perforated cylinder (12), and it, in the form of cylinders, enters the first cascade of the contact drying surface with ceramic coating (7). Due to the rotation of the drum, the particles move along the cascade of the contact surface, and their contact and convective drying occur. Then, the particles reach the second cascade of rollers, and the process is repeated. Convective drying of the particles is realized thanks to the fans (8), which are located on the output side of the drum. Further, the process of granule formation and their combined drying takes place on the cascades of the contact surface, where the particles, rolling over, acquire a spherical shape.

Deposits mined at Lake Burki in the Volyn region were used as sapropelic raw material. Their initial moisture content was $W = 92\%$, and the total organic matter content was 81%. Subsequently, the sapropel was dehydrated by pressing in a compression device and then aged in a geotube according to the methodology described in [15]. As a result, an organic material with a moisture content of $W = 79\%$ was obtained. Concretion powdery phosphorites from the Starovyzhivsky deposit with P_2O_5 content of up to 12% were used as the mineral component. The mixture was prepared in laboratory vessels with organic (sapropel) and mineral (phosphorites) component content of 80% and 20%, respectively.

Perforated surface (1) with a hole diameter of 8 mm and a cylindrical roller (2) (Fig. 2, a) were used to form cylinders from the obtained mixture (3). The particles obtained in this way are shown in Fig. 2, b.

The formed cylindrical particles were placed on a flat oscillating surface with ceramic coating heated to a temperature of $t = 100$ ºC and dried for 20, 25, 30, 35, and 40 minutes. Subsequently, moisture content determination was performed for each of the obtained granule samples using the drying method according to standardized procedures. Additionally, determination of the fractional composition, bulk density, and individual density was carried out using standardized methods.

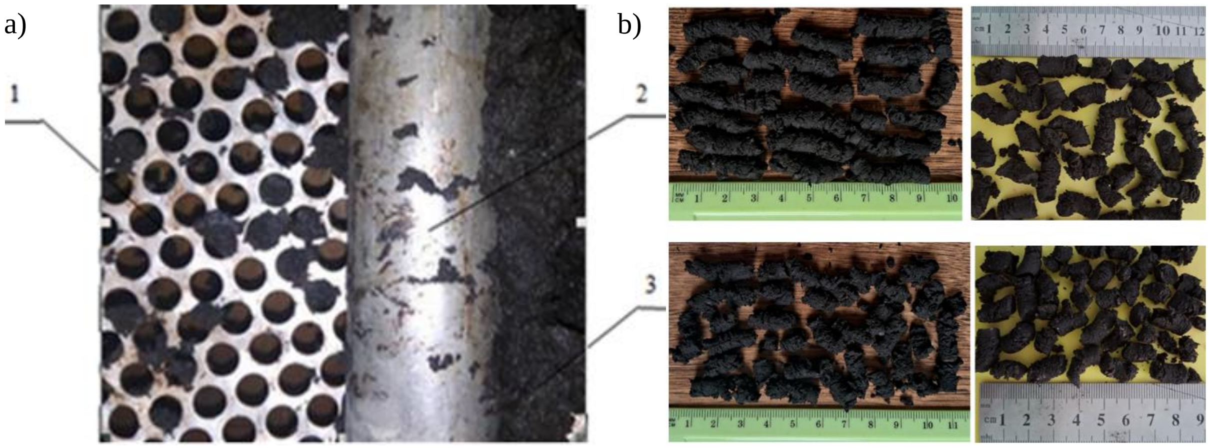

Fig. 2. **Picture of the particle formation process from the organic-mineral mixture**

To investigate the compressive strength of the obtained granules, an extensometer with a flat spring stiffness of 25 N·mm^{-1} was used as a basis. For automation of the applied force fixation to the granule, the device was equipped with a digital displacement indicator (1), allowing the recording of the spring deflection values in Microsoft Excel electronic spreadsheet in real-time mode (Fig. 3).

Fig. 3. **Picture of the setup for testing the granule strength**

The tested granule samples (3) were placed between the movable surfaces of the frame (2). Then, a smoothly increasing load was applied by rotating the handle (4). The increase in load was stopped when the displacement indicator (1) showed a negative increment. The maximum value recorded in the electronic table was considered as the breaking force. The strength of the granule was calculated based on the equivalent area of its cross-section.

Results and discussion

During the drying process on the oscillating surface over time intervals determined by the methodology, the cylindrical granules acquired a spherical shape, and samples of them were obtained with the moisture content provided in Table 1.

Table 1

Moisture content values of the obtained granule samples

Drying time, min	20	25	30	35	40
Humidity of granules *W*, %	59.2 ± 1.1	50.1 ± 0.9	38.3 ± 1.8	29.2 ± 1.6	21.3 ± 1.6

Next was carried out the determination of the static strength of the granules, as well as their bulk and unit density, and particle size distribution for each of the obtained samples. The investigation of the static strength of the granules and particle size distribution was performed with a triple repetition, while the determination of the unit and bulk density was conducted with ten repetitions. Confidence intervals were calculated for the confidence probability value of 0.95 and the Student's coefficient corresponding to the number of repetitions (3 or 10). Curves based on the average values of the obtained parameters are presented in Figures 4 and 5.

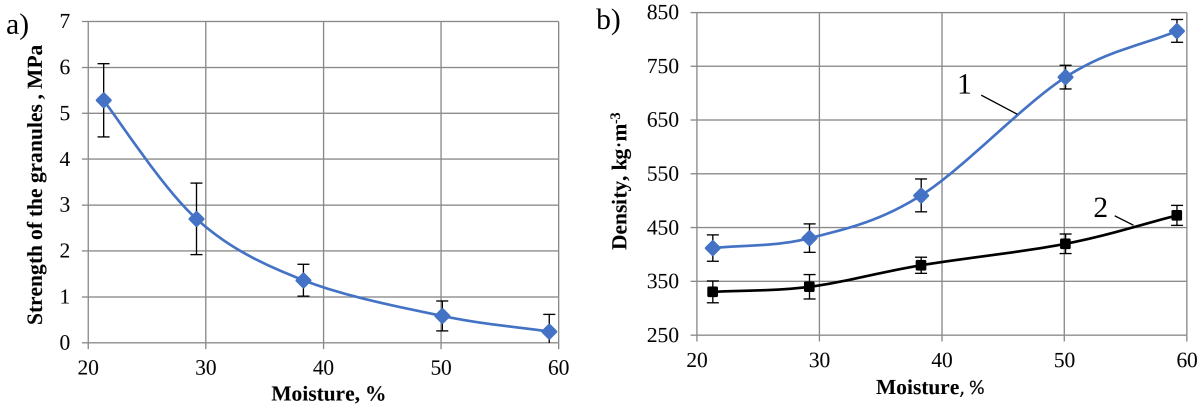

Fig. 4. **Dependence of the static strength of the granules (a) and density (b) on their moisture content:** 1 – unit density; 2 – bulk density

The obtained results indicate that due to the plasticization of the organic-mineral mixture during the extrusion process through the perforated surface, cylindrical particles are formed, which acquire a spherical shape during contact drying on the oscillating surface. Within a drying time of 30-40 minutes, the moisture content of the granules can reach values within the range of 20-30%. At the same time, the static strength of the granules will be in the range of 2 to 5 MPa. This is entirely sufficient for the application of such granules using existing machinery for mineral fertilizers, as indicated in [7], where the required strength of the granules for soil application is 2 MPa. Achieving this specified strength is evidently attained through intensive compaction and strengthening of the surface layers of the granules due to their contact with the heated surface and the high binding properties of the sapropel raw material.

For the moisture range of 20-30%, the density of individual granules ranges from 400-450 kg/m^3, while the volumetric density ranges from 300-350 kg/m^3. These values are 2-3 times lower than those for granules made from compost and animal manure as cited in [16]. However, these values are consistent with those obtained for granules made from sapropel and ash [7]. This indicates the presence of a porous structure in the granules, which creates conditions for the intensive penetration of soil moisture into the granule.

However, an analysis of the histogram of the granule size distribution indicates the presence of particles with moisture content of 21.3% and 29.2% within the 20% fraction with sizes ranging from 1 to 2 mm. Considering the previously mentioned individual density, this can significantly reduce the spread width when using centrifugal spreaders. Therefore, it is advisable to apply such granules locally in rows during seeding or fertilization of agricultural crops.

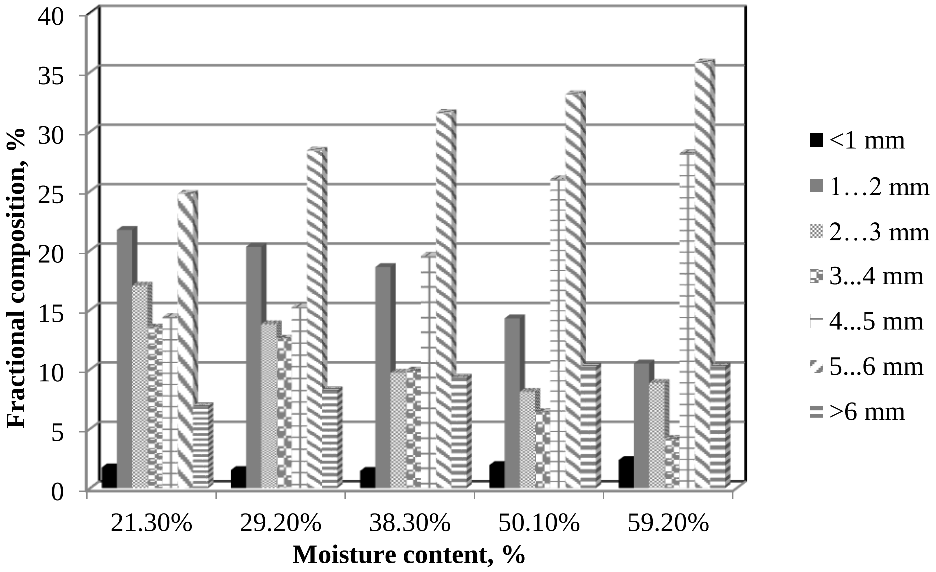

Fig. 5. **Particle size distribution of granules depending on their moisture content**

Conclusions

1. Fertilizers formed on the basis of long-term natural organic sapropel deposits have particular prospects in Ukraine. The main composition of such fertilizers should be supplemented with mineral components from local deposits. Sapropel fertilizers in granulated form provide the highest level of technological efficiency for application.
2. It has been established that due to the plasticization of the organic-mineral mixture during extrusion through the perforated surface, cylindrical particles are formed, which acquire a spherical shape during contact drying on the oscillating surface. Within a drying time of 30-40 minutes, the moisture content of the granules can reach 20-30%. At the same time, the static strength of the granules ranges from 2 to 5 MPa.
3. The density of the obtained individual granules and their bulk density indicate the presence of a porous structure, creating conditions for intensive penetration of soil moisture into the granule. However, the presence of up to 20% of particles with sizes ranging from 1 to 2 mm and a density of 400-450 kg·m^{-3} among granules with moisture content below 29.2% can significantly affect the quality of their dispersion by centrifugal devices. Therefore, it is advisable to apply such granules locally in rows during seeding or fertilizing agricultural crops.
4. The method of obtaining organic-mineral fertilizers presented is promising but requires further research on the use of various types of mineral nutrition components from local deposits in the composition of the granules, as well as the mechanism of influence of these fertilizers on the yield of agricultural crops and soil properties.

Author contributions

Conceptualization, S.Kh. and I.T.; methodology, S.Kh., I.T. and V.T; validation, , S.Kh. and R.Kh; investigation, , S.Kh, I.T. and V.T.; data curation, S.Kh. and I.T.; writing – original draft preparation, S.Kh. and I.T.; writing – review and editing, S.Kh, and R.Kh.; visualization, I.T. and R.Kh. All authors have read and agreed to the published version of the manuscript.

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