STUDY OF SAPROPEL PROCESSING PROCESS IN ROTARY DISPERSER-MIXER

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Abstract. Organic sapropel is a high-quality source of soil humus replenishment and is highly effective when applied to degraded and technogenically contaminated soils. The specific conditions of sapropel deposit formation result in a dispersed structure containing 92-98% water. To utilize sapropel as a solid organic fertilizer, its moisture content must be reduced to 60%, which requires significant energy input. One approach to utilizing organic sapropel in its natural moisture state is treating it with a weak alkaline (or acidic) solution to produce humic fertilizers. To ensure a high-quality reaction between sapropel and alkaline solution, a laboratory-scale rotary disperser-mixer was developed. This design facilitates micro-mixing of naturally moist sapropel with an alkaline solution in an annular channel formed between the rotor and stator. The aim of this study is to determine how the parameters of sapropel treatment in the developed disperser-mixer influence the activation of the humic complex. The study investigated the effects of the alkali solution concentration, the sapropel-to-alkali solution ratio, and the disperser-mixer rotor speed on the treatment process. To assess the effectiveness of the treated sapropel, a laboratory experiment was conducted, growing oil radish with varying fertilizer applications. A four-factor Box-Behnken experimental design was used to develop a mathematical model describing the effect of the treated sapropel on oil radish growth. The results indicate that sapropel processed using the developed rotary disperser-mixer, compared to untreated sapropel, led to a 5-20% increase in oil radish plant height.

Keywords: soil, fertility, organic fertilizers, sapropel, machinery, application.

Introduction

Many studies have confirmed that organic sapropel is a high-quality source of soil humus replenishment [1-3]. The presence of humic substances in sapropel contributes to its radioprotective, accumulative, transport, regulatory, and physiological properties, which determine its effectiveness in restoring degraded and contaminated soils [3-5]. The unique formation process of sapropel deposits results in a dispersed structure with 92-98% water content. During extraction, especially using hydraulic and hydromechanized technologies, the water content in the extracted deposits can reach up to 99% [6; 7]. To ensure minimum economic feasibility for using sapropel as a solid organic fertilizer, its moisture content must be reduced to 60%. However, dehydrating sapropel to this level requires high energy consumption and the application of specialized equipment and technologies.

One alternative to using organic sapropel in its natural moisture state is the production of humic organic-mineral fertilizers (HOMF). Various natural and artificial materials can serve as raw materials for such fertilizers. However, using local natural resources such as peat and sapropel significantly reduces production costs [8-10]. Humic organic-mineral fertilizers are widely produced and used both in Ukraine and internationally. Ukrainian manufacturers offer several sapropel-based humic fertilizers, including “Sapropel,” “Humate Extra” (by Bio Agro Zakhyst), “Humat Kaliiu” (Ukrainian Organics), and “Saprogum” (Zender Ukraine) [11]. Additionally, the German company Humintech provides a wide range of humic fertilizers derived from various organic sources.

Currently, the most widespread is the technology of manufacturing HOMF, which is based on the property of humic acids (HA) to interact with weak solutions of alkalis, mineral acids and their salts to form salts of humic acids - the so-called humates [12]. The main technological component in the extraction of HA is a qualitative reaction, i.e. the achievement of conditions under which the maximum amount of organic matter reacts with the extractant. The desired result is achieved by high mixing speeds at elevated temperatures and pressures in batch dispersers-mixers [13].

The specific structure of sapropel, which differs from peat and lignite, along with its high moisture content (up to 98%), complicates the extraction of HA. Physically bound water creates hydration shells around colloidal particles, which are stabilized by surface tension forces. During mechanical mixing or grinding, achieving continuous micro-scale interaction between the reagent and organic matter of sapropel is crucial to maximizing HA extraction. This goal can be achieved using continuous-flow disperser-mixers, which can be static or mechanically driven [14-16]. A static mixer consists of a hollow pipe or channel with internal partitions that alter the fluid flow structure, inducing secondary transverse flows that enhance the mass and heat transfer. Due to this design, static mixers divide and redistribute

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flow lines using only fluid energy [14; 17]. In contrast, mechanically driven disperser-mixers feature a rotating rotor of various designs within a specially shaped stator. Dispersion occurs as fluid moves through the gap between the rotor and stator [14; 16]. High-shear disperser-mixers, such as those manufactured by Chemineer, are widely used. In water-coal slurry production, dispersion intensifies due to cavitation effects [16]. However, these disperser-mixers require pre-mixing of reagents before operation.

To ensure efficient interaction between sapropel and an alkali (or acid) solution, we have developed a novel disperser-mixer design that eliminates the need for pre-mixing [18]. This design facilitates micro-mixing of naturally moist sapropel ($W = 94 - 96\,\%$) with an alkaline solution in an annular channel formed within the rotor-stator gap (Fig. 1).

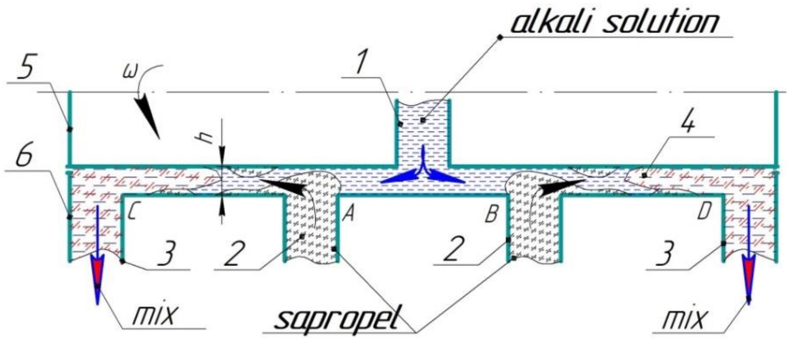

Fig. 1. **Scheme of the working process of mixing sapropel with an alkali solution:**
1 – alkali supply channels; 2 – sapropel supply channel; 3 – mixture discharge channels;
4 – mixing channel; 5 – rotor; 6 – stator

The aim of our study was to determine the effect of sapropel processing parameters on the activation of the humic complex when mixed with an alkali solution in the developed disperser-mixer.

Materials and methods

To conduct the experiments, an experimental setup was designed and manufactured for the treatment of sapropel through intensive mixing with an alkali solution (Fig. 2). The setup consists of a sapropel hopper-tank (1), an alkali solution tank (2), and a disperser-mixer (3). The sapropel is fed into the disperser-mixer by a gear pump (5), while the alkali solution is supplied by a centrifugal pump (6). The rotor of the disperser-mixer is driven by an electric motor (7) through a belt drive (8), and the treated sapropel is collected in a sump (4). A system of bypass valves is incorporated to regulate the flow rates of both sapropel and the alkali solution. This setup allows for studying the influence of the following factors on the treatment process: alkali solution concentration, the sapropel-to-alkali solution ratio in the mixture, and the circumferential speed of the outer surface of the disperser-mixer rotor (3).

During the study, the tank (1) was filled with sapropel, and the tank (2) was filled with an alkali solution. The mixing process proceeded with the treated sapropel accumulating in the sump (4). Once the process reached a steady state (15-20 s), a sample of the treated sapropel was collected, and the actuators of the setup were turned off. Then, using the bypass valves, a new feed ratio between alkali and sapropel was adjusted according to the experimental scheme, the drives were reactivated, and another sample of the treated sapropel was taken.

To change the lye solution to a solution with a different concentration, the lye tank was first flushed by completely filling it with water and activating the lye pump and disperser-mixer drives. The system operated in flushing mode. Next, an alkali solution of the required concentration was introduced, and the experiment was repeated as previously described. The circumferential speed of the outer surface of the disperser-mixer rotor (3) was adjusted by changing the gear ratio of the belt drive (8). The sapropel used in the study had a moisture content of 92% and was extracted from Lake Zyatske, Volyn region. A NaOH solution with a concentration determined according to the experimental plan was used for treatment.

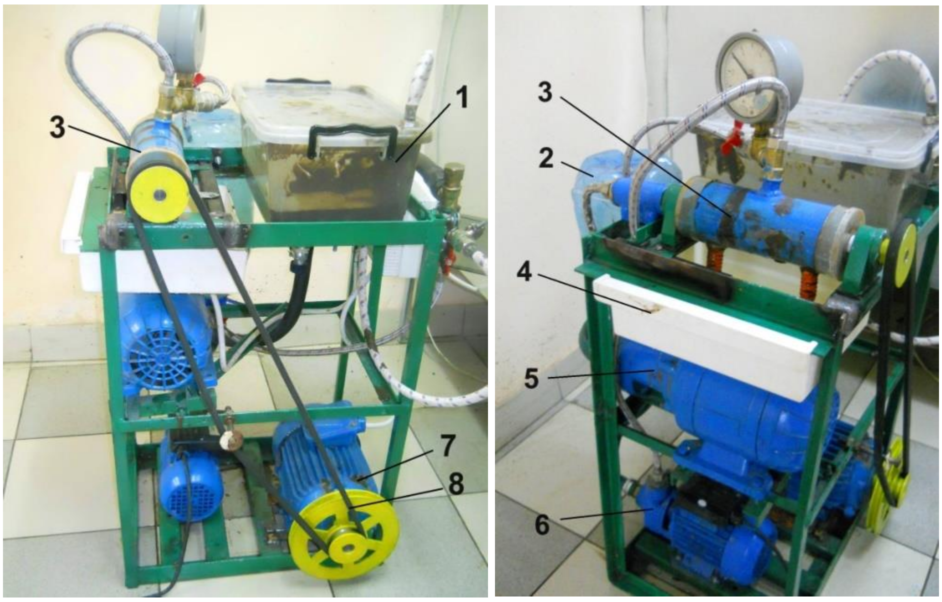

Fig. 2. **Experimental setup for sapropel processing**

Following the methodology outlined in [19], a laboratory experiment was conducted to evaluate the effectiveness of the treated sapropel on agricultural plants, using oil radish cultivation as an indicator. Rectangular containers with a 10-15 mm thick drainage layer were used. Glass partitions divided each container into five compartments, each filled with sandy loamy sod-podzolic soil. In each compartment, four oil radish seeds were sown in a row at a depth of 2-3 cm, corresponding to a seeding rate of 20 kg·ha^{-1} [20]. Treated sapropel was applied in a furrow of the same depth, positioned 3-4 cm away from the seed row. The study also examined the effect of different application rates of the treated sapropel. The amount of the treated sapropel applied in the control section was set according to the experimental scheme. The factors examined in the experiment and their variation limits are presented in Table 1.

For the control experiment, an application rate of 20 t·ha^{-1} of untreated sapropel (with its original moisture content before treatment in the disperser-mixer) was used. After application, the soil was moistened to an average absolute moisture content of 70% and placed under continuous artificial lighting. On the tenth day of the experiment, the height of the oil radish stems was measured with an accuracy of 0.1 mm. Based on the measurement results, the relative growth of oil radish plants was calculated using the following formula:

$$h = (h_s - h_c)/h_c \times 100\,\%, \qquad (1)$$

where h_s and h_c – total height of oil radish plants on the tenth day of the experiment, respectively, fertilized with the treated sapropel and in the control experiment with untreated sapropel, mm.

Fig. 3. **Seed establishment and treated sapropel (left) and condition of oil radish plants at the end of the experiment (right)**

Table 1

Values of the influencing factors studied in the experiment

Levels of variation	Factors			
	Alkali concentration, %.	Application rate, Q, t·ha^{-1}	Relative alkali content, m	Rotor circumferential speed V, m·s^{-1}
Upper (+1)	6	15	1.2	7.85
The main (0)	4	10	1	5.23
Lower (-1)	2	5	0.8	2.61

To develop a mathematical model describing the effect of the treated sapropel on oil radish growth in the form of a regression equation, a mathematical experimental design method was applied for a four-factor experiment, based on a symmetric non-compositional second-order Box-Behnken design.

The significance of the regression coefficients was evaluated using Student's t-test, while the model conformity with the experimental results was assessed by Fisher's F-test.

Results and discussion

As a result of the experiment, the average value of the total height of the oil radish plant in the control experiment was h_c = 24.6 mm. According to the values of the height of oil radish plants in the experimental variants obtained as a result of the experiment, the relative growth was calculated using the formula (1). Based on these values, the coefficients of the regression equation were calculated in Mathcad, their confidence intervals and significance were determined. After removing the insignificant coefficients, the hypothesis of the adequacy of the equation was tested by the Fisher criterion. The calculated value of this criterion with the variance of inadequacy S_n^2 = 5.761 and the variance of reproducibility of the experiment S_y^2 = 2.651 was F^{calc} = 2.173. The tabular value of the Fisher's criterion at the accepted 5% significance, according to [21], was

$$F^{tab}(0.05; f_2; f_1) = 19.43, \quad (2)$$

where f_2 = 19 – number of degrees of freedom of the inadequacy variance;
f_1 = 2 – number of degrees of freedom of variance of the reproducibility of the experiment.

Because,

$$F^{calc.} = 2.173 < F^{tab}(0.05; f_2; f_1) = 19.43, \quad (3)$$

the adequacy of the regression equation by the experimental data is confirmed.

After converting the factors to natural values, we obtained the regression equation (4), on the basis of which the response surface was constructed (Fig. 4)

$$h = -47.93819 + 6.466 \cdot k + 1.9694 \cdot Q + 44.485 \cdot m + 4.17675 \cdot V -$$
$$-0.66175 \cdot k^2 - 0.0648 \cdot Q^2 + 16.45 \cdot m^2 - 0.39931 \cdot V^2 \quad (4)$$

The results of the study showed that the treatment of sapropel in the developed dispersant-mixer provides a relative increase in the stems of oil radish compared to the use of untreated sapropel in the range of 5 to 20%. The maximum relative increase occurs at the concentration of alkali in the solution $k = 4$%, the ratio between sapropel and alkali m = 1.2, application rate Q = 15 t·ha^{-1} and the rotor rotational speed V = 5.23 m·s^{-1}. However, the increase in the ratio between the content of sapropel and alkali solution from m = 1.0 to m = 1.2 does not provide a significant increase in relative growth, but only increases the moisture content of the treated sapropel, which is impractical.

Thus, the influence of all the studied factors on the quality of sapropel processed in the developed disperser-mixer as HOMF was identified. However, the effectiveness of such fertilizers requires further field research to evaluate their long-term impact throughout the entire growing season, across different crops and comparison with the effectiveness of HOMF obtained by other methods.

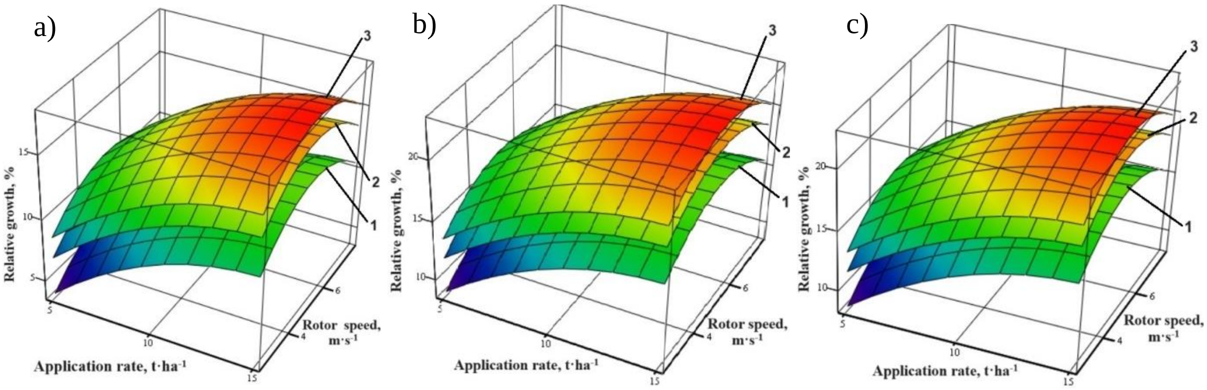

Fig. 4. **Response surface is built by the formula (2):** a – $k = 2\%$; b – $k = 4\%$; c – $k = 6\%$; 1 – $m = 0.8$; 2 – $m = 1.0$; 3 – $m = 1.2$

Conclusions

Increasing the efficiency of using organic sapropel of natural moisture content can be achieved by mixing it with low-concentrated alkali (acid) solutions in a rotary disperser-mixer. The developed design of the disperser-mixer ensures the processing of natural moisture sapropel ($W = 94\ldots96\%$) by its micro-mixing with low concentrated alkali solutions and the production of HOMF. During the laboratory experiment, these fertilizers provided a relative increase in the stems of oil radish in comparison with the use of untreated sapropel in the range of 5 to 20%.

The analysis of the mathematical model of the effect of the treated sapropel on the growth of oil radish shows that the maximum relative growth of oil radish stems occurs at the concentration of alkali in the solution $k = 4\%$, $m = 1.2$, application rate Q = 15 t·ha^{-1} and the rotor rotational speed V = 5.23 m·s^{-1}. Increasing the ratio between the content of sapropel and alkali solution from m = 1.0 to m = 1.2 does not provide a significant increase in relative growth, but only increases the moisture content of the treated sapropel, which is impractical.

Author contributions

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

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