Justification of production indicators of organic fertilizer based on sapropel

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Abstract. The problem facing agricultural scientists is the search for effective ways to develop sapropel for fertilization to increase crop production by increasing soil fertility. One of the most important reserves of organic raw materials are the reserves of lake sapropels. It has been established that sapropel deposits, depending on the depth, have different values of agrochemical and physical properties. Having processed the empirical values of the sapropel characteristics in accordance with the requirements of the technological parameters, we obtained the optimal depths of the layer for industrial development. Its efficiency can be increased when applied together with lower doses of mineral fertilizers. To improve the technological process for the production of sapropel fertilizers, it is necessary to take into account that sapropel should be extracted from a scientifically substantiated layer of the deposit and in its natural state sapropel is not a full-fledged fertilizer; its effectiveness can be increased because of application together with mineral fertilizers. Mixing is one of the most important operations in fertilizer production technology and for this purpose; it is advisable to use a drum mixer.

1. Introduction
One of the problems facing agricultural scientists today is the search for effective ways to develop sapropel for fertilization to increase crop production by increasing soil fertility in zonal science-based farming systems.

Over the past decades, as a result of intensive land use in the soils of the Non-Chernozem zone of Russia with low natural fertility, the humus content has decreased by 0.4% and currently up to 15% of soils contains less than 1% of humus, and 80% of soils from 1% to 2%. To eliminate the humus deficit and increase the yield, it is required to increase the application of organic fertilizers by 40% to the achieved level. [7]

The presence of the existing fodder base, bedding material, methods of keeping animals and developed reserves of peat cannot fully ensure the production of organic fertilizers. One of the most important reserves of organic raw materials is the richest reserves of lake sapropels. [5]

Formulation of the problem

Due to insufficient knowledge of sapropel deposits, the lack of special working bodies, low productivity of dredgers and high book value, long-term work aimed at linking these technologies to sapropel, with the improvement of individual working units, has not found wide application in...
agriculture and in most areas of the region local resources of organic raw materials of sapropels are poorly used. [8]

Therefore, increasing the efficiency of the mechanized process of developing sapropel with improving its quality and environmental performance, the solution of which should be based on new progressive technologies, is of great scientific and national economic importance.

2. Materials and methods
The variety of flora and fauna of the lakes, rich mineral nutrition determine the composition and properties of sapropel. In this regard, there are various sapropel classification systems that determine the main areas of economic use and technological requirements for development. The most important characteristics when choosing sapropel raw materials for fertilization are agrochemical, microbiological, physical properties and composition of the mineral part. These indicators depend on the topographic and soil conditions of the catchment area, depth of occurrence, location from the coast and have a significant impact on the quality of organic raw materials. [10]

As a result of the research, topographic and geodetic work, sounding, testing and viewing of the sapropel deposit were carried out. In order to determine the quantitative and qualitative assessment of the sapropel deposits, the survey and sounding network was carried out using diameters laid perpendicular to the mainline at a distance of not more than 200 m. A picketage of 100 m was divided across all diameters in deep waters and the nature of the mineral bottom. In addition, to reveal the structure of the deposit, all samples were visually examined layer by layer every 0.5 m to determine the type, color and moisture content of sapropel. To determine the quality indicators of the deposit in laboratory conditions, the moisture, ash content, acidity, dispersion, the content of total nitrogen and oxides of calcium, iron, phosphorus and sulfur were determined. [5]

Experimental data have shown that drainless and low-flow lakes have thicker sapropel deposits in comparison with flowing ones. The basins in which the deposits are formed are filled evenly, and the surface layers of the deposits lie almost horizontally. The thickness of the sapropel layer is consistent along the strike and ranges from 4 to 9 meters. The lower layers are represented by sandy-clayey material. Sapropel sediments are uniform in stratigraphy. The most common high-ash organo-mineral sapropel of the siliceous type of brown color. Sapropel ash is colored grayish white with an orange tint of varying intensity depending on depth, which indicates the presence of iron impurities. Natural moisture content in layers varies from 94.5 to 73.8%. In the upper layers, the consistency is viscous; in the lower layers, the sapropel is plastic. The content of oxides of calcium, iron, phosphorus is not significant, the reaction of the medium is weakly acidic. [4]

In flowing water bodies, the processes of sapropelen accumulation proceed more intensively in the spurs in areas with the least water exchange. The surface layers of sediments do not have a clearly horizontal strike and depend on the position of the lake in the relief, the thickness of the reservoir is from 2.5 to 6.7 meters. In the central part of the lake with the best water exchange, diatom sapropels predominate with an insignificant content of calcium, aluminum, phosphorus with a slightly acidic reaction of the medium, ash content 40 - 70%. [16]

We found that sapropel deposits, depending on the depth, have different values of agrochemical and physical properties. The total ash content, nitrogen, iron oxide, calcium, sulfur, acidity and presence of microorganisms are consistent with the industrial genetic classification of sapropels and can be used to produce fertilizers from a scientifically based layer. [13]

However, the value of these properties of the same lake is not constant and depends on the place, time and depth of sampling. Therefore, during the industrial use of sapropel, one should take into account the change in the chemical and microbiological composition with the depth of occurrence. Studies have established that calcium oxide in sapropel has a wide range of values from 1.17 to 20.95%.

Bacteriological analysis showed that the number of microorganisms in 1 g of raw sapropel also has a close relationship with depth varies from 253 to 36 thousand and depends on the type of reservoir,
deep deposits and on the complex of physicochemical and biological processes occurring in the lake during the formation of sapropel. [1]

Such a distribution of characteristics by depth is explained by the process of internal differentiation in the lake during the decomposition of organic matter and the influx of non-chemical and chemical components with wastewater and atmospheric pollution.

The introduction of increased doses of mineral fertilizers and irrigation of crops promotes the removal of nutrients from the soil. Even larger doses of nutrients come from the wastewater of livestock farms. With the development of scientific and technological progress, the process of accumulation of precipitation in lakes is especially progressing. [17]

The upper horizontal layers of the deposit are exposed to higher temperatures, and in the pelogenic layer, the process of decomposition of plant and animal remains with a good content of microorganisms and oxygen takes place. With increasing depth, the influence of the temperature factor decreases, the amount of oxygen decreases, the effect of solar radiation decreases and the conditions for microorganisms worsen. [18] Therefore, with an increase in depth, most microbes are at rest and more obligate anaerobes develop, and the main processes of sapropel formation are inhibited and, mainly, its compaction occurs. Therefore, in order to develop sapropel with high agrochemical and microbiological characteristics, it is necessary to determine the layer of the deposit with the optimal parameters of the acidity level, the content of nitrogen, sulfur, calcium oxide, phosphorus, iron and the presence of microorganisms. [1]

The basis for the mechanized development of sapropel for use in fertilization is the level of organic matter content, physical, agrochemical and microbiological properties, which make it possible to apply effective technology and obtain high-quality fertilizer. [14] Granulometric composition, quantitative content of ash content and moisture content allows creating the necessary structure to substantiate the working bodies and the choice of construction materials. The dispersion of sapropels varies within wide limits and most of them contain few fractions larger than 250 microns, that is, all sapropels are mostly finely dispersed. However, in order to reduce the wear of the working parts of the pump and the pressure-hydraulic supply system, the content of particles with a size from 1 to 2 mm should not exceed 10%, and less than 1 mm should not be less than 90%. In sapropels, the ash content varies over a wide range: organic 6 - 30%, silica, carbonate, mixed - from 30 to 85%. [15]

For the production of fertilizers, the ash content is limited to 50%, however, by agreement with the consumer, an ash content of 70% is allowed. A specific feature of sapropels is their high moisture saturation in their natural state. The natural moisture content of sapropels varies within 73.5 - 97.8%, which is due to the difference in the characteristics of organic matter and the chemical composition of the mineral part. In order to increase the efficiency of the development technology and improve the quality of fertilizers, it is advisable to extract sapropel from the deposit with a moisture content of 75 - 85%. The most important agrochemical property of sapropels is acidity. The acidity level varies widely and ranges from 4.2 to 8.2. [1]

The standard for the production of fertilizers provides for sapropels, the acidity of which is higher than 5. Sapropels of all types are depleted in sulfur, the quantitative content of which does not exceed, as a rule, 1.5-2.0%, it is 80% organic and can be oxidized, which leads to decrease in acidity during the preparation and storage of fertilizers. Therefore, for the production of fertilizers, sapropels with a sulfur content of no more than 3% are recommended. Iron compounds are an integral element of the mineral part of sapropels. During the preparation of fertilizers, oxidation of acidic compounds occurs, their degree of mobility decreases, therefore it is recommended to use sapropels with an iron content of up to 10%.

Calcium in sapropels is highly mobile. This explains the significant agrochemical effect of the action of sapropels containing carbonates. Therefore, sapropels containing more than 20% on dry matter of calcium carbonates can be considered as effective lime materials, and less than 20% (in ash less than 12%) is recommended for use for the preparation of fertilizers. In addition, it is not recommended to use sapropels with a low nitrogen content on a dry matter of less than 1.5%. [12]
To develop the deposit, an integrated approach is required, taking into account all factors of characteristics, in accordance with the requirements for sapropel raw materials for the production of fertilizers.

Based on the research results, we have determined the technological parameters of the properties of sapropel for the development of high quality raw materials from the Savinskoe lake deposit.

Indicators:
- Humidity, 88-79%
- Ash content, 40-50%
- Acidity, 5.5-6.5
- Microbiological composition, 96-43 thousand/g
- Dispersion, 0.38-0.08
- Sulfur, 1.3-0.8%
- Nitrogen, 2.8-1.6%
- Calcium oxide, % 2.9-1.7
- Phosphorus oxide, 0.30-0.25%
- Iron oxide, 4.0-2.3%

Having processed the empirical values of the sapropel characteristics in accordance with the requirements of the technological parameters, we obtained the optimal depths of the layer for industrial development in Savinskoe lake (3.2-5.0 m). [1]

3. The discussion of the results
The movement of the working body in the established layer of the horizon will ensure the quality of sapropel in accordance with the requirements for fertilizer production.

It should be borne in mind that in its natural state sapropel is not a full-fledged fertilizer, it is only a raw material for its production. Its efficiency can be increased when applied together with lower doses of mineral fertilizers. [eleven]

Mixing is a significant and energy-intensive technological operation in the production of sapropel-mineral fertilizers. [2] Therefore, in order to conduct further studies of this process based on the analysis of mixing equipment, we have chosen a continuously operating drum mixer, which has the ability to smooth out fluctuations in instantaneous flow rates of input flows due to the directional organization of their movement inside the apparatus. [6] (Fig.1)
Figure 1. To the drum mixer parameters determination. Where: 1 – drum, 2 – even blade, 3 – odd blade.

The diagram shows that when the drum rotates with a frequency $n < n_{kr}$ the cross-section of the flow of the mixed material in the drum can be represented with a sufficient degree of accuracy as a segment $AaB_1$, which chord $AB_1$ passes to the horizon at an angle $\varphi$, equal to the angle of material collapse. [6]

Segment section area $F$ is equal:
$$F = \pi R^2 \psi,$$

Beams $OA$ and $OB_1$ equal in length to the radius of the drum, limit the area of the segment, forming a central angle $\theta$.

To determine the speed of movement of the mixed mass in the longitudinal direction of the drum $V_n$ need to find the amount of movement $l$ particles of the mixture in one cycle of circular rotation i.e. along the trajectory $BaAB$. 
Figure 2. Scheme of movement of particles in the longitudinal direction in drum-blade mixer.

Figure 2 shows that the quantity \( l_\delta \) is equal \( l_\delta = h \tan \delta \).

Where: 1 – drum; 2 – oblique blade. \( h \) is the height of the mixture particle rise to the point of its separation from the drum wall, \( m \); \( \delta \) is the angle of inclination of the longitudinal axis of the drum. Hence, before finding \( \delta \) need to define \( h \), what can be done from the analysis of the circuit shown in Fig. 2.

\[
h = CO + OE + EF
\]  \hspace{1cm} (1)

With a sufficient degree of accuracy, the value of the sum of the segments \( OE + EF \) can be taken equal \( R \). Line segment \( CO \) from triangle \( OAC \) is equal

\[
CO = CD + DO; \quad CO = R \sin(\gamma + \beta);
\]  \hspace{1cm} (2)

The diagram shows that the sum of the angles \( (\gamma + \beta) \) can be found as the angle difference \( \varphi \) (equal to the angle of material collapse) and \( \eta \) i.e.

\[
(\gamma + \beta) = \varphi - \eta
\]  \hspace{1cm} (3)

Angle \( \eta \) in turn is from the triangle \( OAD \) as angle difference:

\[
\eta = 90 - \theta / 2
\]  \hspace{1cm} (4)

where \( \theta / 2 \) – half center corner.

Therefore, it is necessary to find the value of the central angle. It is known from geometry that the angle made up of the tangent and the chord (in our case \( AB \)) is measured by half of the arc enclosed inside it, i.e. \( \theta / 2 \) of \( \theta \) arc. It is also known that the length of the arc described by the end of the radius is proportional to the value of the corresponding central angle.

Based on the angle \( \theta / 2 \) equal to the angle \( \eta \), i.e. material collapse angle. Substituting the obtained value into expressions 2.36 and 2.39, we obtain that:

\[
CO = R \sin(2\varphi - 90),
\]

and the height

\[
h = R + R \sin(2\varphi - 90), \text{ or}
\]
Then the displacement of the mixture particle from expression (2.35) will be equal to:

\[ l_\delta = R \tan \delta [1 + \sin(2\varphi - 90)] \]  

(6)

To determine the speed of movement of the mixed flow in the longitudinal direction of the drum, it is necessary, in addition to \( l_\delta \), to know the time \( T \), for which this movement occurred.

\[ T = t_1 + t_2 \]  

(7)

where \( t_1 \) – time taken to move a particle along a circular path; \( t_2 \) – parabolic trajectory time (down).

Central corner \( AO_1B_1 \), corresponding to the passage of a circular trajectory by a particle, according to the above calculations and (Fig. 1) is \( 2\varphi \).

When \( n, c \rightarrow 1 \) the duration of one revolution will be \( 1/n \), after which, assuming that on a circular trajectory the particles move at a speed corresponding to the drum rotation speed (we neglect the sliding of particles), we find:

\[ t_1 = \frac{\varphi}{n} \cdot \frac{2\varphi}{360} = \frac{\varphi}{180n} \]  

(8)

The time of passage of a particle along a parabolic trajectory largely depends on the physicomechanical properties of the mixed components included in the mixture.

Parameters such as density, geometrical dimensions of particles, windage, etc. during the mixing process change their properties due to averaging of moisture, stickiness, curling, etc., therefore, the derivation of an analytical equation for determining \( t_2 \) is difficult. [3]

To count \( t_2 \) you should use the empirical formula:

\[ t_2 = \frac{0.345 \sin \varphi}{n} \]  

(9)

From equations 8, 9 the time of one cycle of particle transfer is:

\[ T = \frac{\varphi}{180n} + \frac{0.345 \cdot \sin \varphi}{n} = \frac{\varphi + 62.35 \sin \varphi}{180n} \]  

(10)

Cycles number \( m_1 \), which the particle of the mixture makes in one revolution of the cylinder, we find from the expression

\[ m_1 = \frac{180}{\varphi + 62.35 \sin \varphi} \]  

(11)

Having determined the displacement values of a particle in one cycle and the time of one cycle, we can find the speed of movement of the sapropel-mineral mixture in the longitudinal direction of the drum:

\[ V_u = \frac{l_\delta}{T} = \frac{180R_0 n \cdot \tan \delta [1 + \sin(2\varphi - 90)]}{\varphi + 62.35 \sin \varphi}, \text{m/s} \]  

(12)

where \( R_0 \) – the radius of the circular trajectory on which the particles of the mixture move at an average speed (Fig. 1), so the particles in contact with the wall of the drum are at a great distance from the center of rotation, have a higher speed, and vice versa, the particles at the end of the blade have a lower rotation speed value.
The $R_0$ can be found as the difference between the radius of the drum $R$ and half the blade width $b$, i.e. $R_0 = R - b/2$.

Then expression 12 is transformed into the following form:

$$V_n = \frac{180n(R - b/2) \cdot \tan[1 + \sin(2\varphi - 90)]}{\varphi + 62.35 \sin \varphi}.$$  \hspace{1cm} (13)

4. Conclusion

Based on experimental studies of sapropel deposits in the lake water area and theoretical calculations of the mixing process in a drum mixer, it is possible to develop new and modernize existing production units, taking into account the receipt of agrochemical, microbiological, physical properties of sapropel from the depth of the deposit and mixing units, taking into account obtaining optimal design and technological parameters. [9]

To improve the technological process for the production of sapropel fertilizers, it is necessary to take into account that sapropel should be extracted from a scientifically substantiated layer of the deposit and in its natural state sapropel is not a full-fledged fertilizer; its effectiveness can be increased because of application together with mineral fertilizers. Mixing is one of the most important operations in fertilizer production technology and for this purpose it is advisable to use a drum mixer. [6]

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