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The use of organic farming with the introduction of organic and humic fertilisers

Kazhmukhan Arynov [1], Zhailaubay Zhubatov [1], Gulnur Saruarova [1], Nazgul Nurtaza [1], Ulpan Berikova [1]
[1] Department of Science, LLP "AspanTau LTD"

ABSTRACT

The principles of organic farming are based on the use of agricultural practices that can increase the fertility of the land or keep it at an acceptable level without the introduction of significant amounts of fertilisers and other chemicals that stimulate soil productivity. Each fertiliser has a set of specific characteristics and forms of chemical reactions with the soil, which in turn determines the necessary measures to restore fertility. The novelty of the study is determined by the fact that the composition of fertilisers and their use in the last decade was based on the principles of environmental friendliness, which determine that fertilisers can be used only if the composition of the soil itself is correct. The authors show that the requirements for fertilisers are formulated in such a way that a little additional application of chemicals is required for the soil cover reclamation. The authors consider the use of organic and humic fertilisers. It is shown that the use of humic fertilisers can increase the production yield on the field and organic in the case of crop cultivation under controlled conditions. The practical application of the study will ensure the development of the organic farming system, which will not only provide a spatial and environmental protection but also ensure the socio-economic development of rural areas.

Keywords: Fertiliser, Organic matter, Agricultural production, Phosphate flour, Pulverised fertilisers.

Corresponding Author:

Zhailaubay Zhubatov
Department of Science
LLP "AspanTau LTD"
050024, 255 Auezov Str., Almaty, Republic of Kazakhstan
E-mail: zhubatov5918@nuos.pro

1. Introduction

A new generation of organomineral fertilisers are complex humic preparations obtained by chemical modification of the original raw humic substances, either peat or brown coal [1-7]. At the same time, humic substances undergo significant changes in structure and properties, as a result, the biological activity of the preparations increases [8-13]. The purpose of this study was to obtain biologically active organomineral fertilisers by modifying brown coal and using complexes of humic fertilisers in combination with organic complexes. To attract phosphates into production, studies were carried out on the agglomeration of phosphate flour samples with solutions of ammonium sulphate to obtain NP grade fertiliser. The study is based on the research carried out to develop a method for agglomeration of powdered ammonium sulphate. The agglomeration technology helps to reduce thermal pollution of the environment, increases the concentration of potassium chloride in the plasticiser, and makes it possible to obtain fertilisers with other ratios of phosphorus and potassium components.

The advantages of phosphates include the content in some cases in their composition of glauconite, which contains potassium, and high ecological purity due to the low content of cadmium, lead and arsenic in them, as well as the low radioactivity, which makes it possible to use them without restrictions [14-21]. At the same time, the low content of P2O5 in concentrates and the high dispersion of flour significantly reduce the commercial cost of such fertiliser [22-25]. Based on the results of pilot tests of the use of Kazakhstani and

foreign deposits in the production of phosphates, it was determined that the involvement of phosphate raw materials with P2O5 less than 24% in the production is economically inexpedient [5]. It is advisable to increase the agrochemical cost of this type of phosphate by granulating and modifying them with other plant nutrients [26-32].
It is generally known that the ecological state of a significant part of the world's soils is critical, and the quality of agricultural products is low, which can damage the health and lives of consumers due to the excess of harmful substances that remained after growing crops (nitrates, pesticides, heavy metals and chemical compounds) [33; 34]. At the same time, it should be noted that a nutritious and safe diet is one of the most important factors that determine the health of the population [35-38]. It ensures the normal growth and development of children, contributes to the prevention of diseases, an increase in the life expectancy of people, an increase in working capacity and creates conditions for person’s adaptation to the environment [39-44]. A successful solution to the nutrition problem depends on the creation of a reliable base for the production of high-quality agricultural raw materials, modern food industry and affordable food for all segments of the population [44-46]. At the same time, the focus has been and remains on the quality of food products and food security, which is based on the country's reliable self-sufficiency in basic types of food [11].
The promising market for organic agricultural products is explained by high economic efficiency (50-300% by type of activity) and constantly growing demand in both domestic and foreign markets [47]. Indeed, according to statistics, more than 40% of the population in developed countries are ready to spend $ 300-600 monthly on such products [4].
Significant prospects for the development of organic production are associated with filling the market with organic fertilisers, in particular humic (humates) of natural origin [48-53]. These substances are able to increase the resistance of plants to various unfavourable factors (frost, drought, pesticides), restore soil fertility, increase crop yields, nutrition value of products and their ecological purity, reduce the cost of growing crops, increasing the profitability of agricultural production [54-59].
In particular, the use of humic fertilisers significantly increases the physiological activity of classical liquid nitrogen-containing fertilisers due to their combined use with humic fertilisers by 100% assimilation of all three forms of nitrogen by the plant [60-66]. They have a complex effect on the soil, improving its physical, chemical and biological properties, perform a protective function by binding heavy metals, radionuclides and organic toxicants, thereby preventing their entry into plants [67].
Also, humic fertilisers can be used to destroy crop residues after crushing them and evenly spreading them over the entire area of the field. At the same time, the straw decomposition coefficient increases up to 80%, and the decomposition rate – up to two times in comparison with standard agricultural methods. Embedding 4 tonnes of straw can be equivalent to applying 12-15 tonnes of manure.

2. Material and methods

As a source of humic acids, the authors took brown coal from the Oi-Karagai deposit, located in the territory of the Almaty Region. The original brown coal contains about 3 percent humic acid, which requires oxidation to be used as a raw material. To solve this problem, the oxidation of brown coal with dry carbamide peroxide (hydrogen peroxide clathrate with carbamide) was studied [68]. The oxidation method was carried out in a solid-phase medium – the impact on dry brown coal with carbamide peroxide crystals. The process was carried out on a screw crusher with a crushing size of up to 0.125 mm of a pre-prepared load, consisting of a mixture of brown coal – carbamide peroxide. When the reagents ratio of brown coal: carbamide peroxide is 1.0:0.66, the content of humic acid is increased to 13.1% [69]. The obtained product is enriched with a useful substance for vegetation – carbamide, up to 25% in an air-dried product.
The biological activity of the obtained humic preparation was studied on the germination of cucumber seeds in laboratory conditions. Isolation of the solution of the humic preparation was carried out by leaching with a 1.0% NaOH solution at a temperature of 80°C for 45 minutes, the ratio of the humic preparation and alkali solution is 1:25. The solution was separated from the insoluble carbon ballast by filtration through white ribbon paper. The colour of the solution is black, the pH of the medium is 8-9. For the experiment, aqueous solutions of the specimen with a concentration of 0.0001, 0.0005, 001% were prepared.
In order to attract phosphates into production, studies were carried out on the agglomeration of samples of phosphate flour with solutions of ammonium sulphate to obtain NP grade fertiliser [70]. This proposal is based on the study conducted to develop a method for agglomeration of powdered ammonium sulphate. When

developing the technology of ammonium sulphate agglomeration, the need for grinding ammonium sulphate particles to a size of no more than 0.3 mm was determined and the binding properties of the ammonium sulphate solution were evaluated [71-77]. Studies have established that a solution of ammonium sulphate has astringent properties in a wide range of concentrations: from 1 to 37%, while the water temperature must be maintained (323-358) K. Experiments on the production of granular forms of fertilisers in a semi-dried way were carried out according to the following procedure. Dry weighed portions of phosphate meal and nitrogen fertiliser were mixed. Part of the nitrogen fertiliser was sent to dissolution for the preparation of a plasticiser. Then a part of the plasticiser was fed into the mixer and mixed with dry components. The wet mass was dosed onto a disc granulator and, if necessary, a plasticiser was additionally fed to the disc through a hydraulic nozzle. After the start of granulation, the plasticiser feed was stopped [78-81]. The granulator was stopped when the entire mixture was granulated. The wet granulate was sieved on 1 mm and 5 mm sieves and dried under static conditions. The commercial fraction was transferred for chemical analysis and determination of physical and mechanical characteristics. An ammonium sulphate pulp with the following characteristics was used as a plasticiser in the process of phosphate flour agglomeration: pulp density – 1287 kg/m3; mass fraction of nitrogen in the pulp – 12.1%; mass fraction of (NH4) 2SO4 = 57.04% [82-86].

3. Results and discussion

Experiments to determine the biological activity of humic preparations on the example of testing on cucumber seeds were carried out in accordance with GOST R 54221-2010. The purpose of the method is to determine the increase in germination of agricultural crops (cucumber seeds), the length of stems and roots, as well as the weight of plants under the influence of HP (0.0001%, 0.0005% and 0.001% aqueous solution) in comparison with the control experiment (aqueous solution). The increase in these indicators reflects the biological activity of humic preparations [87-90].

A double pad of filter paper was placed at the bottom of the Petri dish, which was moistened with 10 ml of a humic preparation and distilled water (0.01%, 0.005%, and 0.001%). In the control experiment, the filter paper was moistened with the same volume of distilled water. Seven cucumber seeds, pre-treated with a weak solution of potassium permanganate for 30 min, were sown in the cups. Petri dishes with seeds were placed in an oven in the dark and incubated for 3 days at 29.5°C, and then for another 6 days in the light at room temperature. After 9 days from the beginning of the experiment, the germination of seeds was determined, as well as the measurement of the length of the stems, roots and the mass of plants. Calculations of changes in indicators were carried out as a percentage of control seedlings, five-fold replication. On the second day, all seeds, including the control ones, began to sprout, so the germination rate is 100%.

The biological activity of HP, determined by the increase in the mass of seedlings, Ba(m), was calculated by the formula

$$Ba(m) = \frac{(m-m_1)*100}{m_1} \quad (1)$$

where m – he average mass of seedlings under the influence of HP; m_1 – the average mass of seedlings in control experiments.

The biological activity of HP, determined by the increase in stem length, Ba(s), was calculated by the formula

$$Ba(s) = \frac{(l-l_1)*100}{l_1} \quad (2)$$

where l – the average length of the stems of seedlings under the action of HP; l_1 – the average length of the stems of seedlings in control experiments.

The biological activity of HP, determined by the increase in root length, Ba(r), is calculated by the formula

$$Ba(r) = \frac{(l_2-l_3)*100}{l_3} \quad (3)$$

where l_2 – the average length of seedling root under the action of HP; l_3 – average seedling root length in control experiments.

Table 1. Indicators of germination of cucumber seeds in solutions of a humic preparation (HP)

No.	control (dist. water)		0.0001% HP		0.0005% HP		0.001% HP	
	stem length, cm	root length, cm	stem length, cm	root length, cm	stem length, cm	root length, cm	stem length, cm	root length, cm
1	7.6	20.2	4.8	11.4	8,4	20	6,8	9,6
2	7	10	5.5	7.4	7,2	19	10	8
3	5.2	11.8	5.7	9.2	7,2	18,7	12,4	8,2
4	5.2	8.5	6.8	18.4	6,2	9,7	7	6,5
5	4.5	4.7	6.1	13.5	4,6	12	8,7	7,1
6	4.5	4.7	5.6	10	5,3	8,6	4,7	5
7	4.7	11	5.2	8.9	7	10	1	1
8	2.5	4	8	20.3	6,7	19,2	16,5	8,5
9	5.5	6	8	16.8	8,6	15,4	18,6	9,3
10	5.5	11	6.7	15.3	8,2	14,5	20,6	7
11	8.8	13.2	7	7.5	4,4	8,3	20,4	8,8
12	6.5	14.7	9.3	17.4	6,8	22,3	8,5	7,5
13	6	6.6	7.6	20.1	5,8	15,6	15,5	7
14	6	9.5	6.9	10.2	7,9	18	0,5	0,5
15	5	8.3	6.4	16.8	5,8	17,1	14	8,3
16	5.2	9.7	8	13.7	8	14,7	4	7
17	5.8	9.6	5.6	11.3	5,3	15,2	18,5	9
18	5.8	12.5	4.2	11.2	5,4	17	9	7
19	8	20	6.4	7.9	3,5	8,7	4	7
20	4	7	4.3	5.4	1,5	5,4	4	4
21	0.3	0.5	5.4	16	5,6	7,4	12	9,5
22	6.5	12.8	7.3	14	5,6	11,6	17,7	8,5
23	6.3	16.5	9.1	18.9	5,3	17,8	11,6	6,4
24	0.5	0.4	8.4	20.7	5,2	8,5	8,6	7,7
25	8.4	12.5	9.9	21.8	7,1	17,6	5,6	6,3
26	7	11	8.4	22.1	5,6	12	16,5	7
27	6.2	9.9	7.7	18.2	6,8	16,3	10,5	6,4
28	0.5	0.6	8.2	21.3	5,6	14	0,5	0,5
29	4.6	12.8	7	15.8	8,2	21,4	17,6	8,8
30	5.6	17.5	5.7	10	6,6	20,5	12,4	7,6
31	6.8	13	6.3	11.1	6,5	5,8	8,8	6,7
32	6.6	19.6	5.8	12.4	5	18,6	6,7	4,4
33	5.8	16.4	6.1	13.2	5,1	13,8	11,3	7,2
34	6.2	15.5	7.2	10.9	15,8	25,2	8,5	5,3
35	5	15.3	9.3	17	6,4	20,3	7,8	7
avg., cm	5.42	10.78	6.85	14.17	6,41	14,86	10,31	6,73
avg., %	100	100	126.4	131.4	118,3	137,8	190,2	62,4
weight total, g	7.5		11.3		8.4		7.8	
weight, %	100.0		150.7		112.0		104.0	

The findings presented in Table 1 show that the humic preparation solution has a positive effect on the growth of cucumber seeds [91]. An optimal effect on seed growth is achieved at a HP concentration of 000.1%. The average length of the stems of seedlings is 26.4% longer, the length of the roots is 32.4% longer, the weight of seedlings is 50.7% bigger. Having determined the HP concentration of 000.1% as optimal, further experimental work was carried out to study the effect of gibberellic acid on the biological activity of the humic preparation. For this, a 000.1% solution of the humic preparation was taken as a control and 0.015%, 0.03% and 0.15% solutions of the sodium salt of gibberellic acid were prepared in this solution. Further experiments on growing cucumber seeds in the prepared solutions and estimating the effectiveness of the preparations were carried out as in previous experiments with solutions of a humic preparation [92-95].

All the seeds gave seedlings on the second day of the experiment, so the seed germination rate was estimated at 100%. According to the results of the experiment, it can be confirmed that the sodium salt of gibberellic acid increases the biological activity of the humic preparation by 27.7% (Table 2).

Table 2. Indicators of germination of cucumber seeds in solutions of a humic preparation (HP) with a sodium salt of gibberellic acid (GA).

No.	Control (0.0001% HP)		0.0001% HP+0.015 GA		0.0001% HP+0.03% GA		0.0001% HP+ 0.15% GA	
	stem length, cm	root length, cm	stem length, cm	root length, cm	stem length, cm	root length, cm	stem length, cm	root length, cm
1	7.5	8	10.5	17	8.5	11.5	13.3	6
2	7	11.7	8	13	9.5	7	15.5	8
3	7.5	9.5	7	5	5.6	6	11.5	9
4	7	7	10	11	10	10.5	15.8	8
5	8	10	5	7	7.5	5.5	13	6.5
6	8.5	20	9	13	8	6	14	8
7	7	14.5	4	7	9.5	7	13	6
8	9	7.5	8	11.5	9.8	17	10	8.3
9	7.5	7	9	11	10	9	16	7
10	8	10.5	8	11	8	7	8.3	6.5
11	8.5	17.5	7.5	13	8.3	7.5	10.5	6.8
12	7	7	8	10	9	7.5	14	7
13	7.5	15.3	7	16	8.5	7	11.5	7.5
14	8	8	8	13	9	7.5	10	7
15	8	9	7	9	10	8	12.5	7
16	7.5	12.5	9.5	13	10.5	6	14	6
17	8	10.5	7	13	11.3	8	11.5	6
18	8.5	11	8.5	15	9	6	13.3	6
19	7.5	9.5	9.5	12.5	9.5	9	12	6.3
20	7.5	14.5	7	16	10	4	10	8.3
21	7.5	19.5	7	8.5	9.4	6.5	11.3	7
22	9	12	8	9	10	13.5	10.5	8
23	9	7.2	10	12	10.4	10	13.2	8.2
24	9	8.5	8	10.5	9	12.2	13	6
25	8	8.5	9.7	12.5	8	12.5	12	5
26	9	7	7.5	12	9.5	6.5	13	7
27	8	8.5	9	10	9	9.5	8	5
28	9	13	8.5	12	5	4	9	4
29	9.7	14.5	9.5	11.5	9.5	20.5	12.5	5
30	8.7	7.7	9	9	9	9.5	12	6.5
31	9	10.5	6.5	6.5	10.4	6.5	12.5	7
32	8.5	20.3	9	15	10.7	5.5	10	8
33	8	10.5	6.5	6	9.3	4.5	9.5	6
34	7.5	9.5	7	6	8.7	8.7	12.5	4.5
35	6.5	10.5	8	9.5	10.4	12.3	10	6

avg., cm	8.04	11.09	8.02	11.06	9.14	8.55	11.96	6.71
avg., %	100.0	100.0	99.8	99.7	113.7	106.3	148.8	60.5
weight total, g	11.2		13.6		13.6		14.3	
weight, %	100.0		121.4		121.4		127.7	

The process of phosphate meal agglomeration requires, first of all, determining the optimal degree of grinding of raw materials [96-98]. From the standpoint of the known technology, the qualitative process of agglomeration of phosphate flour is facilitated by the absence of particles with a size of more than 0.4 mm. It is precisely these characteristics that the phosphate flour from a number of deposits corresponds to, they were used as a model substance.

In accordance with the methodology, studies of the agglomeration process were carried out to determine the dependence of the strength of granules on the dispersed composition of raw materials. The wrapping of the agglomerates was carried out in the range of moisture content of the load (9-11) %. The chemical and granulometric composition of the studied samples of phosphate flour is presented in Table 1. For agglomeration, a concentrate of various granulometric composition was used: output – sample 1; fraction less than 0.2 mm – sample 2; fraction less than 0.1 mm – sample 3. According to the findings, it can be noted that the agglomeration occurred in all cases, but better in the first case. Samples 2 and 3 required more time to evenly wet the flour.

Table 3. Chemical and granulometric composition of the studied samples of phosphates

Indicator and unit of measurement	Name of phosphates	
	Sample 1	Sample 2
Mass fraction of total phosphates equivalent to P_2O_5, %	35.4	12.8
Mass fraction of assimilated phosphates equivalent to $P_2O_{5mid.}$, %	17.8	10.3
Mass fraction of water, %	0.9	0.2
Mass fraction of cadmium, mg/kg	0.5	0.3
Mass fraction of lead, mg/kg	99.5	9.5
Mass fraction of arsenic, mg/kg	1.4	3.0
Granulometric composition:		
more than 5 mm, %	-	-
more than 3 mm, %	-	-
more than 2 mm, %	-	-
more than 1.0 mm, %	0.03	0.01
more than 0.63 mm, %	0.06	0.02
more than 0.4 mm, %	23.7	0.03
more than 0.315 mm, %	12.4	0.03
more than 0.2 mm, %	24.2	18.9
more than 0.1 mm, %	24.2	32.7
more than 0.05 mm, %	12.2	20.7
less than 0.05 mm, %	2.6	27.4

In the process of granulation by agglomeration, only physical and mechanical processes occur. Table 4 shows the chemical composition of nitrogen-phosphorus fertiliser samples obtained by agglomeration.

Table 4. Physicochemical composition of granular NP-fertiliser samples obtained from phosphate flour

Indicator and unit of measurement	Sample		
	1	2	3
Mass fraction of total nitrogen, %	2.5	2.1	2.4
Mass fraction of total phosphates equivalent to $P_2O_{5\ mid.}$, %	31.3	32.1	31.6
Mass fraction of assimilated phosphates equivalent to $P_2O_{5mid.}$, %	16.4	17.8	17.6
The ratio of the mass fraction $P2O_{5mid.}$ to mass fraction $P_2O_{5mid.}$, %	52.4	55.3	55.8
Static strength of granules, MPa	3.07	2.68	1.42

As evidenced by the data in Table 4, the resulting product of the NP-2: 31 brand contains 2% N and 31% P_2O_5 and has a high strength of granules, regardless of the initial dispersed composition of phosphate meal. At the same time, the polydisperse composition of the original flour in sample 1 makes it possible to obtain granules of greater static strength, which makes it possible to conclude that it is advisable to grind phosphate flour only to a fraction of less than 0.4 mm [99-106]. The finely dispersed composition of sample 3 requires a greater amount of moisture for the initial moistening of the load and for accurate maintenance of the parameters of the sintering process. In order to verify the results obtained, on the basis of previous experience, studies were carried out on the agglomeration of phosphate rock from the deposit. Phosphate in terms of particle size distribution is represented by a polydisperse fraction of less than 0.315 mm. Table 5 presents an analysis of the resulting fertiliser. The data in Table 5 show that the proposed technology option can also be implemented on other types of phosphate flour, but the low P_2O_5 content in the fertiliser needs to improve its consumer value [107-111].

Table 5. Physicochemical composition of granular NP-grade fertiliser samples obtained from phosphate meal

Indicator and unit of measurement	Analysis result
Mass fraction of total nitrogen, %	1.6
Mass fraction of total phosphates equivalent to $P_2O_{5.}$, %	10.45
Static strength of granules, MPa	2.1

In accordance with the method, studies of the agglomeration were carried out with the determination of the dependence of the strength of the granules on the moisture content of the load in the range of (8-18) %. The studies were carried out on samples of phosphate meal, which in its physical and chemical characteristics is analogous to highly enriched phosphate meal. The chemical and granulometric composition of the studied sample of phosphate flour is presented in the Table 6.

Table 6. Chemical and granulometric composition of the studied samples of phosphate flour

Indicator and unit of measurement	Analysis result
Mass fraction of total phosphates equivalent to P_2O_5, %	17.4
Mass fraction of water, %	1.2
Mass fraction of cadmium, mg/kg	< 0.5
Mass fraction of lead, mg/kg	4.9
Mass fraction of arsenic, mg/kg	5.5
Granulometric composition:	
more than 0.1 mm, %	68.5
more than 0.063 mm, %	7.1
less than 0.063 mm, %	24.2

Analysis of the data shows that the dependence is extremely high. To obtain granules with a strength of more than 1 MPa from phosphate flour of such a dispersed composition, moisture (11-13%) can be recommended. Another important indicator of granular phosphate flour is the yield of the marketable fraction during agglomeration. The experiments carried out under the conditions of the previous values of the moisture content show that the yield of the commercial fraction (1-4) mm has the greatest value when the moisture content of the load is 15%. (Table 7).

Table 7. Output of the marketable fraction of NP 2:16 grade fertiliser

Indicator	Sample							
	1	2	3	4	5	6	7	8
Moisture content, %	8	10	11	11	11.5	14	15	17
Output of commercial fraction 1-4 mm, %	57	54	66	61.5	66	68	71.5	63.5
Strength of granules, MPa	1.15	1.27	1.36	1.46	1.50	1.52	1.89	1.27

At the same time, within the limits of certain optimal values of the moisture content of the load, it became possible to obtain the output of the marketable fraction of more than 50%, which is quite sufficient for the draw back scheme of obtaining fertilisers. It is known that the high content of P_2O_5 in phosphate flour makes it possible to use it as an independent fertiliser. At the same time, an increase in the efficiency of such fertilisation is possible under the condition of joint application with physiologically acidic fertilisers, which are potash. In conditions of minimal energy consumption, the granulation technology can be carried out by agglomeration of powdered materials with the introduction of a wet plasticiser into their composition [112-118]. Preliminary experiments have established that the technological process of pulverised fertilisers agglomeration occurs at a mixture moisture content of (8-15) % which is significantly less than the moisture content of pulps, and the content of small phosphate particles less than 0.071 mm in size is not less than 30% and there are no particles larger than 0.4 mm [119]. Thus, thermal pollution of the environment can be significantly reduced. A feature of the technology for producing phosphorus-potassium fertilisers is a semi-dried granulation method, in which phosphate flour is granulated using a plasticiser based on potassium compounds. The technical solution for the development of a method for agglomeration of powdered potassium chloride is to premix the potassium chloride powder with a 25% aqueous solution of potassium chloride, followed by feeding the moistened mixture into the granulator. When developing the technology for agglomeration of potassium chloride, the need for its grinding to a size of not more than 0.4 mm was determined and the temperature of the aqueous solution of the plasticiser was determined, which was 328K [120-122]. The process of obtaining granular phosphorus-potassium fertiliser in general consists of the following stages: mixing of components, granulation and drying. Obtaining phosphorus-potassium fertiliser was processed on model samples of phosphate flour of the deposit with a P_2O_5 content of at least 20% and potassium chloride with a K_2O content of more than 40% and a $MgCl_2$ content in terms of MgO-4.1%. An aqueous solution of potassium chloride was used as a plasticiser. The granulometric composition of potassium chloride is presented in the Table 8.

Table 8. Granulometric characteristics of potassium chloride

Indicator and unit of measurement	Analysis result
Granulometric composition:	
more than 0.4 mm, %	insufficient
from 0.2 to 0.4 mm, %	34.3
from 0.1 to 0.2 mm, %	28.1
from 0.071 to 0.1 mm, %	6.4
less than 0.1 mm, %	31.2

The granulometric composition of the phosphate flour is presented in Table 9. Since the granulometric characteristics met the requirements for the particle size of the raw materials, less than 0.4 mm, additional grinding of the components was not carried out.

Table 9. Granulometric characteristics of phosphate flour

Indicator and unit of measurement	Analysis result
Granulometric composition:	
more than 0.63 mm, %	insufficient
from 0.315 to 0.63 mm, %	2.9
from 0.2 to 0.315 mm, %	10.8
from 0.1 to 0.2 mm, %	29.8
from 0.063 to 0.1 mm, %	23.6
less than 0.063 mm, %	33.7

According to the methodology, the agglomeration of a mixture of phosphate flour with powder and a solution of potassium chloride was carried out to determine the dependence of the strength of granules on the concentration of potassium chloride solution. The results of analysis of the agglomeration of phosphate flour with potassium chloride-based plasticiser are summarised in the Table 10 [122].

Table 10. Results of studies of obtaining PK-fertiliser by agglomerating phosphate flour and potassium chloride

Plasticiser (aqueous solution of potassium chloride)	Moisture content of the load	K_2O content, %	P_2O_5 content, %	Granule strength, MPa
20%	14.0	13.0	13.4	1.1
21%	14.5	12.8	13	0.41
22%	14.6	13.0	13.05	0.73
25.5%	13.8	13.1	12.94	1.54

As the data in Table 10 indicate, an increase in the concentration of potassium chloride in the composition of the plasticiser has a positive effect on the strength of the fertiliser granules and is limited only by its solubility. The technology option under study also makes it possible to obtain fertilisers with other ratios of phosphorus and potassium components, which undoubtedly expands the capabilities of the technology. The studies carried out to obtain nitrogen-phosphorus and phosphorus-potassium fertilisers based on phosphate flour serve as the basis for processing the technology of phosphate agglomeration to obtain NPK-fertilisers. The research was carried out on a sample of phosphate-glauconite flour from deposit occurrence, which contains up to 23% P_2O_5 (obtained by flotation beneficiation) [123; 124]. Physicochemical analysis of the sample is presented in the Table 11.

Table 11. Chemical and granulometric composition of the studied sample of phosphate-glauconite flour from deposit occurrence

Indicator and unit of measurement	Analysis result
Mass fraction of total phosphates equivalent to P_2O_5, %	22.7
Mass fraction of assimilated phosphates equivalent to P_2O_5, %	10.7
Mass fraction of total potassium equivalent to K_2O, %	7.8
Mass fraction of water, %	0.82
Granulometric composition:	
more than 0.2 mm, %	8
from 0.1 to 0.2 mm, %	53
from 0.063 to 1 mm, %	14
less than 0.063 mm, %	15

Carbamide was used as a nitrogen-containing raw material, and potassium chloride was used as a potassium component. Before conducting research, all components were ground to a fraction of less than 0.4 mm. In accordance with the methodology, a plasticiser in the form of a 60% carbamide solution was introduced into the load [125]. The determination of the plasticiser composition was based on the results of previous studies of the agglomeration of powdered ammonium sulphate with an aqueous solution of carbamide. The entire sample of carbamide was divided into two flows: powder – for preparing the load; liquid – like a plasticiser. A specific feature of the drying process for carbamide-containing fertilisers is the drying temperature no more than 343 K. The dried product dissipated with the release of a commercial fraction of 2 mm – 5 mm. Fractions with particles up to 2 mm and more than 5 mm were combined into a separate sample and, after grinding, used as a recycle. The results of studies on agglomeration of a mixture of nitrogen fertiliser, phosphate-glauconite flour and potassium chloride with a plasticiser based on a carbamide solution to obtain fertiliser are presented in Table 12.

Table 12. Chemical composition of NPK-fertiliser sample based on phosphate flour from the deposit occurrence

Indicator and unit of measurement	Values
Mass fraction of total nitrogen, %	11.1
Mass fraction of total phosphates equivalent to $P_2O_{5.}$, %	15
Mass fraction of assimilated phosphates equivalent to P_2O_5, %	7.2
Mass fraction of total potassium equivalent to K_2O, %	11.0
Mass fraction of water, %	0.75
Static strength of granules, MPa	1.0

Mathematical processing of experimental studies showed that the moisture content of the mixture of powders (w) depending on the nitrogen content in the plasticiser solution (a) and the sum of the components P_2O_5 and K_2O (b) in the powder is described by the first-order regression equation.

$$W = 11{,}648 - 0{,}3709 \cdot a + 0{,}0635 \cdot b \quad (4)$$

The determination factor of equation (4) is $R^2 = 0{,}9743$.

4. Conclusion

Manufacturers of organic agricultural products today have a sufficient selection of organic soil cultivation products that ensure high-quality of production and profitability of farmers' activities. And those agricultural manufacturers who adhere to traditional technologies were able to experiment with alternative production technologies, improving soil structure, product quality, and, consequently, their own financial condition.

The studies carried out confirmed the possibility of obtaining not only 11:15:11 grade fertiliser but also a whole class of complex fertilisers based on phosphate flour with a P2O5 content of more than 80% and powdered carbamide, ammophos, potassium chloride, where one of the fertilizer components is used as a plasticizer. The developed technology of the semi-dried method of agglomeration also made it possible to work out such brands of NPK-fertilisers as 19:19:19, 16:16:16, 20:10:0 based on the powdery components of the fertiliser with an aqueous solution of carbamide. At the same time, it was determined that the amount of the plasticiser is extreme, depending on the composition of the fertiliser. The use of agglomeration technology has made it possible to significantly reduce the thermal pollution of the environment. Also, the use of this technology contributed to an increase in the concentration of potassium chloride in the composition of the plasticiser, which can positively affect the strength of fertiliser granules and will be limited only by its solubility. This method also makes it possible to obtain fertilisers with other ratios of phosphorus and potassium components, which expands the capabilities of the technology.

It has been shown that by exposing brown coal poor in humic acid composition to dry carbamide peroxide during fine crushing of the load, by leaching oxidised coal enriched with nitrogen-containing fertiliser (carbamide) with a solution of 1% sodium hydroxide and adding the sodium salt of gibberellic acid, it is possible to obtain an organic fertiliser with high biological activity.

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