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Influence of diatomite and its combinations with manure on the fertility of leached black earth soil (chernozem) and on the yield of vegetable crops

Elena Evgenievna Kuzina, Alexander Nikolaevich Arefyev* and Evgeny Nikolaevich Kuzin

Penza State Agrarian University, Federal State Budgetary Educational Institution of Higher Education, 440014, Penza, Russian Federation
**Corresponding author:* aan241075@yandex.ru

Abstract

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The development and implementation of technological methods for eliminating and preventing progressive anthropogenic degradation in agrolandscapes using local raw materials and agro-ore in agricultural practice is an urgent area of modern agriculture. In this regard, the objective of the research was to study the effect and aftereffect of diatomite and its combinations with manure on the fertility of leached black earth soil (chernozem) and the yield of vegetable crops. The studies were carried out in the first agricultural soil region of the Penza region in the period from 2014 to 2018. In the experiment, diatomite from the Korzhevsky deposit in the Penza region was used as a silicon-containing fertilizer. It was established that the humus content in the second year of action of manure and of diatomite in combination with manure exceeded the initial values by 0.17-0.24%. In the first year of the experiment, the use of diatomite in the norm from 2 to 6 t/ha in combination with manure in the norm of 60 t/ha ensured the transfer of soil from a class with a weakly acid reaction to a class with a medium reaction close to neutral. The number of water-resistant units against the background of the combined action of diatomite and manure exceeded the control by 15.3-18.3%. The combined effect and aftereffect of diatomite and manure increased the yield of winter garlic by 45.9-57.9%, and of carrots – by 29.6-45.1%.

Keywords: agronomical ore; manure; winter garlic; carrots; fertility; yield

Introduction

The agricultural use of arable land in the conditions of a deficit of energy and material resources under the modern farming system has led to a decrease in potential and effective soil fertility and a decrease in crop productivity. Over consolidation, loss of humus and calcium, structural destruction, acidification, decreased water holding capacity and other degradation processes are widespread (Dessalew et al., 2017; Kuzina et al., 2018).

The use of chemical and biological ameliorants increases the productivity of crops, reduces harmful anthropogenic effects on the soil, and improves its fertility (Shah et al., 2019; Colombari et al., 2018; Matychenkov et al., 2002). Therefore, the study of the possibility of using local, cheaper mineral resources as fertilizers and ameliorants is an actual area of research. Of the local agro-ore, diatomite, dolomite powder, natural zeolites, marl, etc. can be used in large volumes. The combination of local agronomical ores with organic fertilizers is important in increasing their effectiveness

as fertilizers and chemical ameliorants (Kulikova, 2010; Kulikova et al., 2015).

Methods and Materials

The objective of the research was to study the effect of diatomite and its combinations with manure on the fertility of leached black earth soil (chernozem) and the yield of winter garlic and carrots. To solve this problem, a field experience was laid: 1. Without diatomite and manure (control); 2. Manure 60 t/ha; 3. Diatomite 2 t/ha; 4. Diatomite 4 t/ha; 5. Diatomite 6 t/ha; 6. Diatomite 2 t/ha + manure 60 t/ha; 7. Diatomite 4 t/ha + manure 60 t/ha; 8. Diatomite 6 t/ha + manure 60 t/ha.

The studies were conducted from 2014 to 2018 in the first agropedalogical area of the Penza region. The experiment was repeated three times, the plots in the experiment were placed by the method of randomized repetitions. In the experiment, diatomite from the Korzhevsky deposit located in the Nikolsky district of the Penza region with the following element content (in oxide form, % of absolutely dry matter) was used as a silicon-containing fertilizer: H_2O – 3.14; SiO_2 – 80.42; Al_2O_3 – 8.01; Fe_2O_3 – 2.46; CaO – 0.26; MgO – 0.78; K_2O – 1.00; P_2O_5 – 0.04. Half-rotted cattle manure was used as organic fertilizer. The content of nitrogen in manure was 0.49%, of phosphorus – 0.22%, of potassium – 0.51%. Diatomite and manure were introduced in the main tillage. Winter garlic Bogatyr and carrot Nantskaya were cultivated in the experiment. The direct action of diatomite, manure and of diatomite and manure combinations was used by winter garlic, and carrots were cultivated against the background of aftereffect.

The beginning of the vegetation resumption of winter garlic in 2015 was noted on April 12. During the period from the 2nd decade of April to the 3rd decade of July, 178.4 mm of precipitation fell. The minimum rainfall (8.3 mm) was recorded in May. The maximum rainfall during the vegetation period of 2015 fell in July (127.9 mm), which was 67.4 mm higher than the annual average. The average daily air temperature in 2015 varied from 5.5°C (April) to 22.0°C (June). In April, the temperature was at the level of long-term average. From May to July, the average daily air temperature exceeded the annual average by 1.9-4.3°C.

During the growing season of vegetables in 2016, 240 mm of rain fell. During the growing season, the distribution of precipitation was uneven. So, 84 mm fell in May, 23 mm – in June, 23 mm – in July, 25 mm – in August. In May and July, the rainfall was 40.4-47.5 mm higher than the annual average. June was arid, rainfall was 29.6 mm below the norm. The average daily temperature was above normal and varied in the range from 14.9°C (May) to 22.8°C (August).

In 2017, 176 mm of precipitation fell, which amounted to 72.4% of the norm. During the growing season, the distribution of precipitation was uneven. So, 23 mm fell in May, 55 mm – in June, 86 mm – in July, 12 mm – in August, with a norm of 50; 63; 65; 65 mm, respectively. Air temperature during the growing season ranged from 13.0°C in May to 20.4°C in August. In May, the air temperature was 5.8% below the norm, in June – by 10.2%, in July it exceeded the norm by 3.7%, and in August – by 19.3%.

During the growing season of vegetables in 2018, the amount of precipitation was 198 mm, which amounted to 95.2% of the annual average. During the growing season, the distribution of precipitation was uneven. The maximum amount of precipitation fell in April (66 mm) and in July (71 mm), which amounted to 69.2% of their total amount. In May, the rainfall was 28 mm, in June – 17 mm, in August – 16 mm. The air temperature during the growing season varied from 16.6°C in May to 21.9°C in July. In May, July and August, the air temperature was above the norm by 1.9-2.9°C. In June, the air temperature was within normal limits (17.9°C).

Results and Discussion

The intensive use of soils with low volumes of organic and mineral fertilizers, the use of heavy machinery, and the development of water erosion have led to a significant decrease in the humus content in black earth soils in recent years (Goryanin et al., 2019).

According to average data, the upland soils of the plains of the black earth soil zone annually lose 0.6-1.0 tons of humus per hectare, as a result of agricultural use. The rate of change in the humus content depends on the type of use of arable land.

One of the methods for stabilizing the improvement of the humus content of black earth soils is the use of organic fertilizers.

In the arable layer of leached black earth soil without diatomite and manure, the average humus content in garlic crops was 7.40% for three years, 7.39% in carrot crops, with the initial value – 7.41% (Table 1).

The studies showed that the use of diatomite in leached black soil stabilized the humus content in the arable layer. Under the unilateral action and aftereffect of various diatomite norms, the humus content in the arable layer remained practically unchanged and amounted to 7.42% on average for three years after harvesting garlic, after harvesting carrots it was 7.43%, with the initial content of 7.41%.

Table 1. The influence of diatomite and manure on the content of humus in leached black earth soil, % (average for three years)

Variant	The initial content of humus	Winter garlic		Carrot	
		humus	deviation	humus	deviation
1. Without diatomite and manure (control)	7.41	7.40	-0.01	7.39	-0.02
2. Manure 60 t/ha	7.41	7.55	0.14	7.58	0.17
3. Diatomite 2 t/ha	7.41	7.42	0.01	7.43	0.02
4. Diatomite 4 t/ha	7.41	7.44	0.03	7.45	0.04
5. Diatomite 6 t/ha	7.41	7.45	0.04	7.46	0.05
6. Diatomite 2 t/ha + manure 60 t/ha	7.42	7.58	0.16	7.61	0.19
7. Diatomite 4 t/ha + manure 60 t/ha	7.41	7.60	0.19	7.63	0.22
8. Diatomite 6 t/ha + manure 60 t/ha	7.40	7.59	0.19	7.64	0.24
Least significant difference (LSD) p = 0.05		0.12		0.15	

Manure in the first year of its action increased the humus content in crops of winter garlic by 0.14%, in the second year in crops of carrots by 0.17%.

The maximum humus content was noted when using diatomite in combination with manure. The humus content in these experimental variants was 7.58-7.60% in winter garlic crops, and 7.61-7.64% in carrot crops. The increase in relation to the initial content against the background of the direct action of diatomite in combination with manure was 0.16-0.19%, and against the background of the aftereffect – 0.19-0.24%.

The reaction of the medium is one of the integral characteristics of the level of soil fertility. The reaction of the soil has a complex effect on agrochemical, agrophysical and biological properties, and, therefore, on the content of mobile nutrients in the soil and on the growing conditions of plants. Agricultural use of land significantly disturbs the balance between the supply and removal of bases, which leads to the development of acidity (Arefyev et al., 2017).

The introduction of fertilizers and chemical ameliorants into the soil allows to regulate the soil reaction in the direction desired for the cultivated crops.

The studied soil was characterized by a slightly acid reaction of the medium. The value of metabolic acidity (pH_{salt}) in the variant without the use of diatomite and manure averaged 5.35 units for winter garlic crops, and 5.33 units for carrot crops (Table 2).

Against the background of the direct effect of manure at the rate of 60 t/ha, the pH_{salt} value in the crops of winter garlic was 5.71 units, and against the background of the aftereffect in the crops of carrots – 5.79 units. The increase in relation to control was 0.36 in the first case and 0.46 in the second.

With the unilateral action and aftereffect of diatomite in norms from 2 to 6 t/ha, a tendency to a decrease in metabolic acidity was noted. The pH_{salt} value exceeded the control after harvesting winter garlic by 0.03-0.10 units, after harvesting carrots by 0.05-0.16 units.

Table 2. The effect of diatomite and manure on pH_{salt} in leached chernozem, % (average for three years)

Variant	Winter garlic		Carrot	
	pH_{salt}	deviation from the control	pH_{salt}	deviation from the control
1. Without diatomite and manure (control)	5.35	–	5.33	–
2. Manure 60 t/ha	5.71	0.36	5.79	0.46
3. Diatomite 2 t/ha	5.38	0.03	5.38	0.05
4. Diatomite 4 t/ha	5.42	0.07	5.44	0.11
5. Diatomite 6 t/ha	5.45	0.10	5.48	0.16
6. Diatomite 2 t/ha + manure 60 t/ha	5.75	0.40	5.86	0.53
7. Diatomite 4 t/ha + manure 60 t/ha	5.80	0.45	5.92	0.60
8. Diatomite 6 t/ha + manure 60 t/ha	5.84	0.49	5.99	0.66
Least significant difference (LSD) p = 0.05		0.20		0.18

The action and aftereffect of diatomite in combination with manure led to a more significant decrease in soil acidity, which was associated with the presence of calcium and magnesium bases in manure. In the first year of action of diatomite in the norms from 2 to 6 t/ha in combination with manure in the norm of 60 t/ha, the pH_{salt} value was 5.75-5.84 units after harvesting winter garlic, and in the second year, after harvesting carrots – 5.86-5.99 units. The value of pH_{salt} against their background significantly exceeded the control in the crops of winter garlic by 0.40-0.49, in the crops of carrots – by 0.53-0.66.

The role of soil structure in creating the most favorable conditions for water, air and food regimes is considered to be universally recognized in the cultivation of crops.

The processes of structure formation in soils precede under the influence of physicomechanical, physicochemical, chemical and biological factors. The main role in structure formation belongs to biological and physicochemical factors.

As the research results showed, the direct effect of manure had a definite influence on the content of water-stable aggregates in the arable layer. The content of water-stable aggregates against the background of the direct effect of manure was 60.4%, against the background of the aftereffect – 64.1%, exceeding the control after harvesting winter garlic by 7.2%, after harvesting carrots by 12.9% (Table 3).

The number of water-stable aggregates with the unilateral action and aftereffect of diatomite varied after harvesting winter garlic from 55.3% (diatomite 2 t/ha) to 56.8% (diatomite 6 t/ha), after harvesting carrots from 54.0 to 56.5%. The increase in relation to the control variant against the background of direct action was 2.1-3.6%, against the background of the aftereffect – 2.8-5.3%.

The highest effect on the restructuration of an agronomically valuable structure in the arable layer of leached black soil was ensured by the combined use of diatomite and manure. The number of water-stable aggregates against their background on average for three years of research was 62.6-64.5% after harvesting winter garlic and 66.5-69.5% after harvesting carrots. The increase in relation to the control variant against the background of direct action of diatomite in combination with manure was 9.4-11.2%, against the background of the aftereffect – 15.3-18.3%.

An important characteristic of the structural state of the soil is the structural coefficient. On average, over three years of the research, the structural coefficient in the arable layer of leached black soil in the variant without diatomite and manure was 1.14 after harvesting winter garlic, and 1.05 after harvesting carrots (Table 4).

In the arable layer under the direct action of manure in the norm of 60 t/ha, the structural coefficient was 1.53, exceeding the control by 0.39. In the second year of action of manure, the structural coefficient was 1.79 on average over the study period. Deviation from control was 0.74.

With the unilateral action of diatomite in the norms from 2 to 6 t/ha, the structural coefficient varied from 1.18 (diatomite 2 t/ha) to 1.31 (diatomite 6 t/ha). The increase ranged from 0.04 to 0.17 compared to the control variant. Against the background of unilateral aftereffect of diatomite, the structural coefficient varied in the range from 1.17 to 1.30, exceeding the control by 0.12-0.25.

The maximum values of the structural coefficient over the years of the study were recorded against the background of the complex effect and aftereffect of diatomite and manure. After harvesting the garlic, the structural coefficient for these

Table 3. The effect of diatomite and manure on the structural state of leached black soil (chernozem), % (average for three years)

Variant	Winter garlic		Carrot	
	water-stable aggregates > 0.25 mm	deviation from the control	water-stable aggregates > 0.25 mm	deviation from the control
1. Without diatomite and manure (control)	53.2	–	51.2	–
2. Manure 60 t/ha	60.4	7.2	64.1	12.9
3. Diatomite 2 t/ha	55.3	2.1	54.0	2.8
4. Diatomite 4 t/ha	56.3	3.1	55.8	4.6
5. Diatomite 6 t/ha	56.8	3.6	56.5	5.3
6. Diatomite 2 t/ha + manure 60 t/ha	62.6	9.4	66.5	15.3
7. Diatomite 4 t/ha + manure 60 t/ha	63.8	10.6	68.4	17.2
8. Diatomite 6 t/ha + manure 60 t/ha	64.5	11.2	69.5	18.3
Least significant difference (LSD) p = 0.05		2.8		3.2

experimental variants varied on average for three years from 1.67 to 1.82. The increase in relation to the control variant was 0.53-0.68. The structural coefficient against the background of aftereffect of diatomite with manure varied in the range from 1.99 to 2.28, exceeding the control by 0.94-1.23.

In the arable layer of leached chernozem without the addition of diatomite and manure, the steady-state density for an average of three years of research was 1.21 g/cm^3 (Table 5).

The action and aftereffect of manure at a rate of 60 t/ha contributed to the softening of the arable layer. The value of the steady-state density against the background of its effect was 1.14 g/cm^3 after harvesting winter garlic, and against the background of aftereffect – 1.12 g/cm^3 after harvesting carrots and was lower than the control in the first case by 0.07, in the second – by 0.09 g/cm^3.

The unilateral action of diatomite reduced the steady-state density of the arable layer by 0.01-0.04 g/cm^3 after harvesting winter garlic and by 0.02-0.05 g/cm^3 against the background of the aftereffect after harvesting carrots. The value of the steady-state density, depending on the norm of diatomite, varied against the background of direct action in the range from 1.17 (diatomite 6 t/ha) to 1.20 g/cm^3 (diatomite 2 t/ha), and against the background of aftereffect – from 1.16 to 1.19 g/cm^3.

The highest effect on the softening of the arable layer over three years of the research was noted against the background of the action and aftereffect of diatomite in combination with manure. The magnitude of the steady-state density in these experimental variants varied after harvesting garlic in the range from 1.09 (diatomite 6 t/ha, manure 60 t/ha) to 1.12 g/cm^3 (diatomite 2 t/ha, manure 60 t/ha), and after harvesting carrots – from 1.07 to 1.10 g/cm^3. The decrease in relation to the control was 0.09-0.12 in the first case and 0.11-0.14 g/cm^3 in the second.

A rational fertilizing system that meets the natural and organizational and economic conditions of a farm is a leading factor in increasing yields and improving its quality, increas-

Table 4. The effect of diatomite and manure on the structural coefficient of leached black soil (average over three years)

Variant	Winter garlic		Carrot	
	structural coefficient	deviation from the control	structural coefficient	deviation from the control
1. Without diatomite and manure (control)	1.14	–	1.05	–
2. Manure 60 t/ha	1.53	0.39	1.79	0.74
3. Diatomite 2 t/ha	1.18	0.04	1.17	0.12
4. Diatomite 4 t/ha	1.29	0.15	1.26	0.21
5. Diatomite 6 t/ha	1.31	0.17	1.30	0.25
6. Diatomite 2 t/ha + manure 60 t/ha	1.67	0.53	1.99	0.94
7. Diatomite 4 t/ha + manure 60 t/ha	1.76	0.62	2.16	1.11
8. Diatomite 6 t/ha + manure 60 t/ha	1.82	0.68	2.28	1.23
Least significant difference (LSD) p = 0.05		0.14		0.19

Table 5. The effect of diatomite and manure on the steady-state density of leached black soil, g/cm^3 (average over three years)

Variant	Winter garlic		Carrot	
	steady-state density	deviation from the control	steady-state density	deviation from the control
1. Without diatomite and manure (control)	1.21	–	1.21	–
2. Manure 60 t/ha	1.14	0.07	1.12	0.09
3. Diatomite 2 t/ha	1.20	0.01	1.19	0.02
4. Diatomite 4 t/ha	1.18	0.03	1.17	0.04
5. Diatomite 6 t/ha	1.17	0.04	1.16	0.05
6. Diatomite 2 t/ha + manure 60 t/ha	1.12	0.09	1.10	0.11
7. Diatomite 4 t/ha + manure 60 t/ha	1.09	0.12	1.08	0.13
8. Diatomite 6 t/ha + manure 60 t/ha	1.09	0.12	1.07	0.14
Least significant difference (LSD) p = 0.05		0.04		0.03

ing soil fertility and maintaining it (Jędrszczyk et al., 2019; Kulikova et al., 2013).

On average, over three years of the research, the yield of winter garlic in the variant without adding diatomite and manure was 6.65 t/ha. The direct effect of manure at a rate of 60 t/ha increased the yield by 2.47 t/ha, or by 37.1%. Diatomite in the norm of 2 t/ha increased productivity by 0.65 t/ha, or by 9.8%. With the unilateral action of diatomite, the maximum yield of winter garlic was formed on the varinats using ameliorants in the norms of 4 and 6 t/ha. On average, over three years, the yield on these variants was 7.90-8.05 t/ha, exceeding the control by 1.25-1.40 t/ha, or by 18.8-21.1% (Table 6).

The highest effect on the yield was exerted by diatomite, used in combination with manure. The yield of winter garlic ranged from 9.70 (diatomite 2 t/ha + manure 60 t/ha) to 10.50 t/ha (diatomite 6 t/ha + manure 60 t/ha). The increase in relation to the control variant was 3.05-3.85 t/ha, or 45.9-57.9%.

According to the data presented in Table 7, the carrot yield in the variant without diatomite and manure averaged 27.5 t/ha for the three years.

Against the background of unilateral aftereffect of manure, the carrot yield for an average over the three years was 33.4 t/ha, exceeding the control by 5.9 t/ha, or by 21.5%.

The results of the research showed that the aftereffect of diatomite at a rate of 2 t/ha did not provide a significant increase in carrot yield. A significant increase in carrot yield was noted against the background of aftereffect of diatomite in the norms of 4 and 6 t/ha. On average, over the three years of the research, carrot yield against the background of aftereffect of diatomite in the norms of 4 and 6 t/ha varied in the range from 31.95 to 33.75 t/ha, exceeding the control by 4.45-6.25 t/ha, or 16.8-22.7%.

The most significant effect on carrot yield was exerted by the aftereffect of diatomite at the rates of 4 and 6 t/ha in combination with manure. On average, over the three years of the research, the carrot yield in these variants varied in the range from 38.33 to 39.89 t/ha, exceeding the control by 10.83-12.39 t/ha, or by 39.4-45.1%.

Conclusion

The action and aftereffect of manure and diatomite in combination with manure made it possible to create a pos-

Table 6. The effect of diatomite and manure on the yield of winter garlic (average for 2015-2017)

Variant	Yield, t/ha	Deviation from the control	
		t/ha	%
1. Without diatomite and manure (control)	6.65	–	–
2. Manure 60 t/ha	9.12	2.47	37.1
3. Diatomite 2 t/ha	7.30	0.65	9.8
4. Diatomite 4 t/ha	7.90	1.25	18.8
5. Diatomite 6 t/ha	8.05	1.40	21.1
6. Diatomite 2 t/ha + manure 60 t/ha	9.70	3.05	45.9
7. Diatomite 4 t/ha + manure 60 t/ha	10.32	3.67	55.2
8. Diatomite 6 t/ha + manure 60 t/ha	10.50	3.85	57.9
Least significant difference (LSD) p = 0.05		0.30	

Table 7. The aftereffect of diatomite and manure on carrot yield (average for 2016-2018)

Variant	Yield, t/ha	Deviation from the control	
		t/ha	%
1. Without diatomite and manure (control)	27.50	–	–
2. Manure 60 t/ha	33.40	5.90	21.5
3. Diatomite 2 t/ha	29.70	2.20	8.0
4. Diatomite 4 t/ha	31.95	4.45	16.8
5. Diatomite 6 t/ha	33.75	6.25	22.7
6. Diatomite 2 t/ha + manure 60 t/ha	35.65	8.15	29.6
7. Diatomite 4 t/ha + manure 60 t/ha	38.33	10.83	39.4
8. Diatomite 6 t/ha + manure 60 t/ha	39.89	12.39	45.1
Least significant difference (LSD) p=0.05		2.30	

itive balance of humus in the arable layer of leached black soil (chernozem). The humus content in the second year of action of manure and of diatomite in combination with manure exceeded the initial values for an average of the three years of the research by 0.17-0.24%.

The use of diatomite with the rates from 2 to 6 t/ha in combination with manure at a rate of 60 t/ha provided a significant increase in pH salt and the transition of the soil from a class with a weakly acid reaction to a class with a medium reaction close to neutral already in the first year of their application.

The most significant impact on the restructuration of the lost structure was made by the integrated use of various norms of diatomite with manure. The number of water-stable aggregates in these variants exceeded the control by 15.3-18.3% on average for three years of research, and the structural coefficient was 0.94-1.23.

The greatest effect on the softening of the arable layer was exerted by the complex effect and aftereffect of diatomite and manure. The value of the steady-state density in the second year of their action was lower than the control by 0.11-0.14 g/cm^3.

The combined effect and aftereffect of diatomite and manure had the most significant influence on the yield of winter garlic and carrots. The yield of winter garlic against the background of their direct action increased by 45.9-57.9% and the yield of carrots against the background of their aftereffect increased by 29.6-45.1%.

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