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RESEARCH ARTICLE
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Organo-mineral Fertilizers Improve the Growth and Yield of Lingonberries (*Vaccinium vitis-idaea* L.) on Peat in the Non-Chernozem Zone of Russia

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ABSTRACT

The study evaluates a newly developed granular organo-mineral fertilizer (OMF) for cultivated lingonberry (Vaccinium vitis-idaea L.) of Russian breeding—'Kostromichka', 'Kostromskaya Rozovaya', 'Rossiyanochka', and 'Rubin'. The OMF contains NPK 8–8–8 with micronutrients (Cu 0.4%, Fe 0.5%, Zn 0.2%) and vermicompost inoculated with spore-forming bacteria of high biological activity. Experiments were conducted on a high-moor peat substrate (pH 2.9–3.4) under the agroclimatic conditions of Moscow (Non-Chernozem Zone of Russia). The factorial design comprised four cultivars × four fertilizer treatments, with three replicates and 10 plants per replicate. Data were analyzed by one- and two-way ANOVA ($\alpha = 0.05$). Application of the developed granulated OMF improved the peat substrate's agrochemical status and produced the highest fruit yields (412.3–988.5gm^{-2}), exceeding alternative fertilizers— a complex mineral product ("Rastvorin for Ericaceae") and a commercial organo-mineral product ("Gumi Omi – Acid-Loving Shrubs")—by 1.7–9.0%. The most favorable morphophysiological traits were recorded in September under OMF, including photosynthetic productivity (4.85mg CO_2 dm^{-2}h^{-1}), leaf area (2.50dm^2 plant^{-1}), total root surface area (73.5m^2), effective absorptive root surface (60.2m^2), root biomass (35.8g), and leaf biomass (51.4g). Relative to comparators, OMF increased lingonberry yield by 1.6–9.0% and enhanced fruit quality, raising dry matter by 1.6–2.0%, soluble sugars by 0.8–1.5%, and vitamin C by 1.3–2.2mg 100g^{-1} fresh weight. Overall, the developed OMF ensured an adequate and season-long supply of macro- and micronutrients to V. vitis-idaea, thereby improving plant performance and productivity on peat substrates in the Non-Chernozem region.

Keywords: Fertilizers, Lingonberry, *Vaccinium vitis-idaea,* Berry plants, Cultivar, Substrate, Peat, Soil micro-biology, Microorganisms.

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INTRODUCTION

At present, many countries across the world are facing severe degradation of agricultural lands, extensive soil contamination by pesticides and industrial wastes, and a progressive decline in natural soil fertility. These adverse processes collectively reduce crop quality and productivity, ultimately triggering large-scale economic and environmental crises (Maximillian et al., 2019; Hossain et al., 2020; Cheryatova & Yembaturova, 2022; Landa-Acuña et al., 2022). Therefore, a new form of agriculture is needed to ensure food and biosecurity. An effective solution to the current agricultural crisis is the revival of organic farming, the essence of which is to use the potential of natural living systems, in particular microorganisms (Ajeng et al., 2020). The development of scientifically based fertilization systems is crucial for a comprehensive increase in the yield of berry crops. The use of chemical fertilizers is certainly a guarantee of high yields, but their irrational use has a number of negative consequences for the environment, including pollution of groundwater and the atmosphere due to the accumulation of compounds in the soil that are not typical for the natural environment and changes in the natural soil microbiome (Balakrishnan et al., 2020; Brevik et al., 2020; Cardarelli et al., 2020; Phour et al., 2020; Ukaogo et al., 2020; Ateş & Kivan, 2021; Minuț et al., 2023; Alori et al., 2024). The growing need to provide the population with environmentally friendly food products from fruit and berry crops has led to the need to develop alternative fertilizer technologies. Thus, organo-mineral fertilizers have

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recently attracted attention due to their high role in sustainable agriculture, despite the slow release of nutrients. Organo-mineral fertilizers mainly contain microorganisms that have a positive effect on the microbiome of agricultural soils, thereby increasing their natural fertility, and also protect plants from biotic and abiotic stresses (Jacoby et al., 2017; Mącik et al., 2020; Bhat et al., 2022; Chan et al., 2022).

It has been established that the use of organo-mineral fertilizers plays an important role in improving the soil and the quality of fruit crops (Xiong et al., 2021; Kumawat et al., 2022; Wilhelm et al., 2022; Ye et al., 2022; Sadvakasova et al., 2023; Vincze et al., 2024). Organo-mineral fertilizer application has been shown to alter soil nutrient profiles and soil microbial activities (Zhong & Cai, 2007; Bacon et al., 2015; Loeppmann et al., 2016; Jansson & Hofmockel, 2020; Seleiman et al., 2023; Alenazi et al., 2024). Many researchers have reported changes in soil microbial diversity and increases in microbial abundance after fertilizer application (Bhardwaj et al., 2014; Wagg et al., 2014). For example, long-term fertilizer application alters soil microbial diversity and community composition, which significantly affects soil enzymatic activity (Sinsabaugh et al., 2008; Su et al., 2015). Studies have shown that the application of organo-mineral fertilizers increases the input of organic carbon (OC) into the soil, which strongly stimulates the growth of heterotrophic microbes. The application of organo-mineral fertilizers provides readily available nutrients for both plants and microbes and stimulates the overall microbial population in the soil (Sabir et al., 2021).

Today, there is a growing interest of consumers in berry crops of the genus *Vaccinium* all over the world. Lingonberry (*Vaccinium vitis-idaea* L.) from the Ericaceae family is valued for the high nutritional and medicinal properties of berries, which contain a wide range of biologically active substances beneficial to human health. Numerous scientific studies in vivo and in vitro have shown the anti-inflammatory, antimicrobial, antidiabetic, antioxidant and anticancer effects of lingonberry berries on the human body (Vilkickyte et al., 2020; Ilesanmi et al., 2023). It is also important to note that lingonberry extract induced apoptosis of human leukemia cells in laboratory experiments (Wang et al., 2005). It has been experimentally established that regular consumption of lingonberry berries helps treat and prevent brain aging and neurodegenerative diseases in humans (Hossain et al., 2016; Kelly et al., 2017; Reichert et al., 2018; Vilkickyte et al., 2022).

In the conditions of the Central zone of Russia, where the lingonberry crop is gaining increasing economic importance due to the insufficient supply of the fruit market due to the unstable yield of wild berries, the reduction of berry reserves due to the negative impact of anthropogenic factors and the imperfection of the organization of berry collection and processing (Uskov, 2015; Tyak et al., 2016; Makarov et al., 2019; Nabieva, 2019; Timoshok & Skorokhodov, 2019; Martynyuk et al., 2023). The possibility of growing lingonberries on peat soils (Holloway et al., 1982; Holloway, 1984; Yakovlev & Vogulkin, 2003; Turtiainen et al., 2007; Morozov, 2008; Chudetsky et al., 2022a; Tyak et al., 2022; Chudetsky et al., 2023a) allows rational use of depleted peat deposits and drained swamps. At the same time, for the harsher climatic conditions of the European part of Russia, it is important to grow locally bred cultivars (Chudetsky et al., 2023b; Makarov et al., 2023b), which have greater winter hardiness compared to well-known cultivars of European selection. In this regard, for the cultivation of lingonberries on an industrial scale, it is necessary to develop and improve agricultural technologies for cultivation. It is known that the cultivation of lingonberries using a scientifically based system of complex fertilizers will not only reduce the duration of growing planting material, but also increase the yield of commercial products and improve the quality of fruits. In connection with the above, studies to identify the effect of a fertilizer complex on the biometric indicators of *V. vitis-idaea* in the conditions of central Russia are relevant. Currently, both in the world and in the Russian fertilizer market, there are very few complex fertilizers for increasing the productivity of lingonberries, taking into account the characteristics of the species. The development and testing of a new type of organo-mineral fertilizer for plantation cultivation of lingonberries is an urgent task of modern organic farming for the conditions of the Non-Black Earth Zone of Russia.

We have developed a new type of organo-mineral fertilizer (OMF) with the composition NPK 8:8:8, Cu 0.4%, Fe 0.5%, Zn 0.2%. A distinctive feature of this fertilizer composition is that, in addition to the necessary of macro- and microelements, it contains specific microbial consortium with spore forms of bacteria that have a high biological activity in processes of mineralization of complex substances, conversion of organic and mineral phosphates into a form accessible to plants and fixation of atmospheric nitrogen. A trial batch of the product was manufactured at Buyskiy Himicheskiy Zavod (Russia), where microorganisms are grown independently, and submitted for testing for conducting real research. This composition was first tested on lowbush blueberry (*Vaccinium angustifolium* Ait.) crops and showed effectiveness in growing on acidic high-moor peat on a plantation scale (Makarov et al., 2024). The purpose of the research is to study the effect of a new developed organo-mineral fertilizer on the agrochemical characteristics of peat substrate and the biological characteristics of *Vaccinium vitis-idaea* plants in the conditions of the Non-Chernozem Zone of Russia.

MATERIALS & METHODS

The research was carried out on the territory of the Arboretum named after R.I. Schroeder, of the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy (northwestern part of Moscow, Russian Federation) in 2022-2025. The climate is moderately continental. The variety testing plot of berry crops is located on a total area of 0.2ha (N 55.82908°, E 37.54562°), with a flat relief. The parent material is moraine loam, overlain by a light silty–sandy loam (40–50 cm thick). The soil cover is predominantly sod-podzolic soil, typical of the mixed-forest zone of the European part of Russia, formed under natural pedogenic processes and influenced by land use. The sod horizon is 5–40 cm thick, with pH_{KCl} 5.0–5.5 (Makarov et al., 2023a). The objects of the study are lingonberry (*Vaccinium vitis-idaea* L.) plants of 4 cultivars of Russian selection (Kostromichka, Kostromskaya Rozovaya, Rossiyanochka, Rubin). The planting material was obtained by clonal micropropagation and adapted to non-sterile conditions (*ex vitro*) (Makarov et al., 2021 & 2022; Chudetsky et al., 2022b). Plants aged 3 years, 15-20cm high for each cultivar, were planted in 2nd ten-day period of April 2022 in an amount of 10pcs. for each experimental variant (cultivar × fertilizer variation) in 3 replications in trenches (50cm wide and 40cm deep) filled with high-moor peat (pH 2.9-3.4). The distance between rows is 1.5m, the distance between plants in a row is 0.3m. A drip irrigation system was used; additional watering in the first year of vegetation was done as the peat dried out, and every 3 days in the first 14 days after planting. To combat weeds, the spaces between the rows were mulched with wood chips and pine sawdust, and the rows with plantings were weeded by hand (Fig. 1).

Fig. 1: Fragment of *Vaccinium vitis-idaea* plantings on a peat substrate in the Arboretum named after R.I. Schroeder (Moscow, Russia).

Weather conditions during the planting period were favorable. For the period 2023–2024, the average long-term data (for 1961–1990) (Kobysheva et al., 2001) were exceeded by 2.4°C in average monthly temperature and by 248 mm in precipitation during the active growing season (Table 1). A feature of the winter periods of 2022–2023 and 2023–2024 was the large amount of precipitation, which exceeded the average long-term value by 177.7mm and 163.4mm, respectively. Spring in 2024 was characterized by a sharp change in weather, from temperatures above +20°C in the 2nd–3rd ten-day periods of April to a sharp cold snap to –7°C in the 1st ten-day period of May; July was consistently hot, with daytime temperatures of at least +28°C.

Table 1: Meteorological conditions on the territory of the Arboretum named after R.I. Schroeder (Moscow, Russia) during the study period

Month	Average monthly air temperature, °C				Average monthly precipitation, mm			
	2022	2023	2024	Average perennial	2022	2023	2024	Average perennial
January	−5.4	−4.7	−10	−9.3	67.7	35.7	49.9	11.0
February	−0.8	−4.1	−4.4	−7.7	39.7	42.7	60.7	8.0
March	−0.5	1.4	2.0	−2.2	18.3	64.9	9.4	8.0
April	5.8	9.9	11.0	−5.8	77.3	37.7	46.5	9.0
May	10.6	12.8	12.9	13.1	75.1	33.3	36.0	8.0
June	18.8	16.9	20.1	16.6	48.9	78.2	166.3	11.0
July	20.6	18.5	22.4	18.2	90.7	151.2	92.2	12.0
August	22.2	19.8	19.2	16.4	3.1	39.7	34.4	10.0
September	10.1	15.3	18.0	11.0	79	10.4	10.6	11.0
October	7.2	5.4	7.9	5.1	59	114.9	77.3	10.0
November	−0.8	0.7	1.6	−1.2	40.1	87.9	74.6	12.0
December	−4.1	−4.4	−2.1	−6.1	130.3	83.8	54.9	12.0

Fertilizers were applied to the soil at a dose of $55.6gm^{-2}$ (5g per 30×30cm landing spot) in the 3rd ten-day period of April using the "Pottiputki" planting pipe. Plant placement is randomized. The characteristics of fertilizes used in the experiment are given in Table 2. The option without applying fertilizer was considered as a control.

For each treatment, the total content of mobile forms of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) was measured. Studies of the chemical composition of fruits were carried out using generally accepted methods in plant biochemistry (Ermakov, 1987; Sedov & Ogoltsova, 1999). To determine the microelement composition of fruits, samples weighing 250g were ground to a paste-like state using a blender Waring 800S (Waring, USA) and homogenized by stirring for 30mins. To determine the microelement composition of the solid phase of the samples, part of the resulting ground mass was centrifuged in a laboratory centrifuge Eppendorf Centrifuge 5804 (Eppendorf, Germany) for 10mins at a rotor speed of 3000rpm. The crushed mass of samples and the solid phase samples were laid out in a layer 3mm thick on a steel baking sheet covered with polyethylene film, frozen in a freezer Indesit SFR 100 (Indesit Company SpA, Italy) for 20h at −24°C and dried for 24h in a food sublimator Pharm 1 (Lyomachines, Russia) at +40°C, a chamber pressure of 100Pa, and a condenser temperature of −40°C. The resulting dry samples were ground to a powder in a porcelain mortar and sifted through a nylon sieve with a mesh size of 1mm. Samples weighing 0.1g were placed in autoclaves Wein 2 (Hanhi, Russia) and dissolved in 10mL of 7% HNO_3 at +180°C using a microwave sample preparation system. The resulting solutions were diluted 100 times with deionized water. The content of macro-elements (Ca, K, Mg, P) and microelements (B, Cu, Fe, I, Mn) was determined by Zeeman atomic absorption method, a flame technique (Skurikhin & Tutelyan, 1998), in prepared samples of substrate, plants, and fruits and its solid phase using atomic absorption spectrometer Shimadzu AA-7000F/AAC (Shimadzu Corp., Japan) (wavelength in the range from 248.3 to 766.5nm; detection limits in the range of 0.000004 to 0.02mg L^{-1}).

Table 2: Characteristics of the fertilizer-application options

Fertilizer name	Manufacturer	Composition										Additional components	pH
		Ratio of mobile forms			Contents of elements, %								
		N	P	K	Cu	Fe	S	Zn	B	Mn	Mo		
Complex mineral fertilizer "Rastvorin for Ericaceae" (Ericaceae fertilizers)	Buyskiy Himicheskiy Zavod, Russia	20	16	10	0.01	-	5.5	0.01	0.01	0.1	0.001	-	3.0
Complex organo-mineral fertilizer "Gumi Omi – Acid-loving Shrubs" (Gumi Omi)	Bashinkom, Russia	3	7	6	0.01	-	25	0.03	0.01	-	-	Soil microorganisms; fermented chicken manure; potassium humates – 0.4-0.6%; fulvic acids – 0.08-0.11%	3.1
Developed organo-mineral fertilizer (OMF) for lingonberry	Author's development	8	8	8	0.4	0.5	-	0.2	-	-	-	Vermicompost containing spore forms of bacteria *Bacillus subtillis* Ch- 13, *B. mucilaginosus*, and *Azotobakter chroococcum*	2.8

The study of the processes of growth, development, and formation of the harvest of lingonberry when using fertilizers was carried out in the conditions of vegetative experience in accordance with generally accepted methods (Dospekhov, 2011). Morphometric indicators, physiological and biochemical factors, and photosynthesis productivity of plants were studied using the Tyurin–Lukashek method: the carbon content of the leaf sample was determined; the leaves were then kept in the light for at least 2–3h; the carbon content was then determined again; the amount of organic matter formed was determined as the difference between the second and first determinations, expressed per unit of leaf surface per unit of time (Tretyakov et al., 1990; Vinogradova & Smirnova, 2014). The surface of plant roots was measured using the Sabinin–Kolosov method based on the concept of the adsorption nature of roots at the initial stage: a solution of methylene blue was used as the adsorbed substance; the absorption of the solution was determined by the change in the concentration of the experimental solution when the root system was immersed in a methylene blue solution 3 times for 90 seconds; the absorption surface of the roots was determined based on the amount of methylene blue absorbed by the roots (1mg of methylene blue solution covers 1.1m² of the adsorbent surface) (Vinogradova & Smirnova, 2014). The number of the main physiological groups of microorganisms was taken into account in accordance with the recommendations set out in E. Szegi's manual (Szegi, 1979) on solid nutrient media: ammonifiers – meat-peptone agar (MPA); micromycetes – Chapek medium; solvent phosphate – glucose-aspartic agar (GAA); nitrogen fixators – Ashby medium.

Statistical analyses were performed in Statistica v10.0.1011 (StatSoft) and Microsoft Excel 2021. Two-way ANOVA was applied with the following fixed factors: for morphological and physiological traits—A: fertilizer treatment; B: observation period (month); for yield and mean fruit mass—A: fertilizer treatment; B: cultivar. Where applicable, models included main effects and the A × B interaction. Pairwise differences among treatment means were evaluated using Fisher's least significant difference at $\alpha = 0.05$ (LSD_{05}).

RESULTS

An agrochemical and microbiological analysis of substrates, an assessment of the morphological and physiological parameters, yield, and fruit quality of *V. vitis-idaea* plants on the site, an analysis of the content of useful elements in the substrate, plants, and fruits using fertilizers were carried out.

Agrochemical and Microbiological Characteristics of Substrates

Agrochemical analysis of substrates with the introduction of various types of fertilizers for growing lingonberries confirmed a greater accumulation of mobile compounds of N, P and K in the variant using a developed composition of organo-mineral fertilizer (Table 3). Therefore, the phosphorus content increased by 4.4–9.7mg, potassium by 31.2–35.0mg, and nitrogen by 15.5–21.3mg.

Table 3: Agrochemical indicators of the soil when using various types of fertilizers for growing *Vaccinium vitis-idaea* on peat in the conditions of the Arboretum named after R.I. Schroeder (Moscow, Russia)

Variation	pH	Content of mobile forms, mg kg^{-1}		
		Nitrogen total	Phosphorus	Potassium
Control (peat)	2.9-3.4	<2.4	15.20±1.18	48.50±2.54
Peat + Rastvorin for Ericaceae	3.5	8.20±0.75	20.50±1.75	51.30±3.59
Peat + Gumi Omi	3.2	7.00±0.65	19.30±1.41	47.50±0.46
Peat + Developed OMF for lingonberry	3.7	23.70±1.98	24.90±2.02	82.50±5.62
LSD_{05}	-	0.204	0.362	0.586

The dynamics of the number of the main physiologically valuable groups of soil microorganisms in the substrate was also determined when using different fertilizer compositions (Fig. 2).

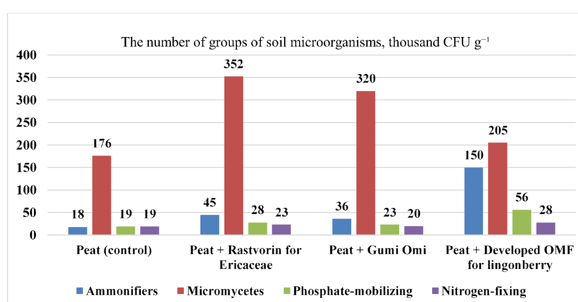

Fig. 2: Dynamics of the number of the main physiologically valuable groups of soil microorganisms when using different types of fertilizers on peat in the conditions of the Arboretum named after R.I. Schroeder (Moscow, Russia).

In treatments receiving complex mineral fertilizers ("Rastvorin for Ericaceae" and "Gumi Omi"), the substrate microbiota was dominated by micromycetes (320–352 $\times 10^3$CFUg^{-1}). Heterotrophic ammonifying bacteria numbered 36–45 $\times 10^3$CFUg^{-1}, while nitrogen-fixing and phosphate-solubilizing bacteria were comparatively low (23–28 $\times 10^3$CFUg^{-1}). Application of the developed organo-mineral fertilizer (OMF) shifted the bacterial–fungal balance: ammonifying bacteria increased to 150 $\times 10^3$CFUg^{-1} (3.3–4.2-fold higher than with the other fertilizers), fungal counts declined modestly to 205 $\times 10^3$CFUg^{-1}, and micromycete activity remained above the control. Together, these changes indicate a more favorable rhizosphere environment for lingonberry growth under OMF.

Morphophysiological Parameters of Plants

As a result of the research, the development of a powerful root system with high indicators of the working adsorbing surface of lingonberry plants on a substrate with the introduction of the developed composition of organo-mineral fertilizer was noted (Table 4).

In the variant with the developed composition of organo-mineral fertilizer, lingonberry plants developed an active working adsorbing root surface during the growing season, which reliably exceeded the indicators of the variant with the organo-mineral fertilizer Gumi Omi by 10.0–14.7% and the mineral fertilizer Rastvorin for Ericaceae by 22.8–30.1%. At the same time, the root mass increased by 10.54% and 8.61%, respectively. Root system performance underpinned the functioning of the shoot. With complex fertilizers, lingonberry exhibited a significant increase in photosynthetic productivity—by 1.99mg CO_2 dm^{-2} h^{-1} with "Gumi Omi" and by 1.98mg CO_2 dm^{-2}h^{-1} with "Rastvorin for Ericaceae"—accompanied by only a minor increase in leaf area per plant. The developed organo-mineral fertilizer (OMF) produced the highest photosynthetic rates across the growing season (3.15–4.85mg CO_2 dm^{-2}h^{-1}). By contrast, control plants grown on unfertilized peat showed consistently lower values than all fertilizer treatments.

The reliability of the obtained data on the main morphological and physiological parameters of *V. vitis-idaea* plants (photosynthesis productivity, leaf area of the plant, total and working adsorbent surfaces of roots, root weight) when using fertilizers is confirmed by the results of the ANOVA analysis (F statistic value > F critical value; p-value < 0.05) (Table 5).

Table 4: Morphological and physiological parameters of *Vaccinium vitis-idaea* plants when using fertilizers on peat in the conditions of the Arboretum named after R.I. Schroeder (Moscow, Russia) (for all cultivars in average for 3 years)

Fertilizing variation (factor A)	Month (factor B)			
	June	July	August	September
Photosynthesis productivity, mg CO_2 dm^{-2} h^{-1}				
Peat (control)	2.61±0.24	3.12±0.30	3.25±0.31	4.02±0.38
Peat + Rastvorin for Ericaceae	2.73±0.25	3.35±0.32	3.61±0.34	4.71±0.45
Peat + Gumi Omi	2.54±0.22	3.28±0.31	3.40±0.32	4.53±0.44
Peat + Developed OMF for lingonberry	3.15±0.29	3.77±0.35	3.82±0.35	4.85±0.47
LSD_{05}, mg CO_2 dm^{-2}h^{-1}: A = 0.38; B = 1.06; AB = 0.40				
Leaf area of the plant, dm^2				
Peat (control)	1.02±0.16	1.06±0.11	1.58±0.14	1.95±0.17
Peat + Rastvorin for Ericaceae	1.07±0.16	1.15±0.12	2.13±0.20	2.72±0.25
Peat + Gumi Omi	1.15±0.18	1.18±0.12	1.85±0.16	2.35±0.21
Peat + Developed OMF for lingonberry	1.28±0.23	1.81±0.17	2.32±0.21	2.50±0.23
LSD_{05}, dm^2: A = 0.83; B = 1.44; AB = 1.20				
Total surface of roots, m^2				
Peat (control)	37.80±2.41	42.70±4.40	46.20±4.05	50.40±4.78
Peat + Rastvorin for Ericaceae	46.20±3.68	53.40±4.52	58.70±5.16	62.20±5.75
Peat + Gumi Omi	41.90±3.75	45.20±4.43	51.30±4.65	56.10±5.22
Peat + Developed OMF for lingonberry	50.30±4.52	60.10±5.58	68.50±6.12	73.50±6.70
LSD_{05}, m^2: A = 0.94 ; B = 1.35; AB = 1.27				
Working adsorbent surface of roots, m^2				
Peat (control)	28.50±2.06	32.80±2.80	36.50±3.04	39.10±3.60
Peat + Rastvorin for Ericaceae	37.90±2.74	44.80±3.73	48.20±4.40	52.50±4.48
Peat + Gumi Omi	32.50±2.38	40.30±3.51	42.20±4.12	48.70±4.35
Peat + Developed OMF for lingonberry	41.70±3.65	49.50±4.26	54.90±5.02	60.20±5.62
LSD_{05}, m^2: A = 0.90; B = 1.56; AB = 1.40				
Root weight, g				
Peat (control)	9.50±0.79	12.10±1.10	19.50±1.55	21.90±1.90
Peat + Rastvorin for Ericaceae	15.30±1.12	20.20±1.58	26.30±2.40	30.70±2.85
Peat + Gumi Omi	12.40±1.10	16.50±1.44	21.70±2.06	28.10±2.56
Peat + Developed OMF for lingonberry	20.40±1.29	24.80±2.12	30.50±2.82	35.80±3.20
LSD_{05}, g: A = 0.79; B = 1.34; AB = 1.06				
Stem weight, g				
Peat (control)	49.50±3.62	55.20±5.12	61.30±5.45	70.10±6.72
Peat + Rastvorin for Ericaceae	58.20±5.22	62.40±5.60	70.80±6.68	79.50±7.67
Peat + Gumi Omi	52.30±4.48	60.10±5.68	67.50±6.34	76.20±7.35
Peat + Developed OMF for lingonberry	61.50±5.87	67.30±6.44	72.40±7.04	81.30±7.88
LSD_{05}, g: A = 0.88; B = 0.52; AB = 0.47				
Leaf weight, g				
Peat (control)	12.50±1.11	20.30±1.19	25.10±2.10	30.90±2.70
Peat + Rastvorin for Ericaceae	18.30±1.45	26.50±1.54	32.80±2.92	40.70±3.56
Peat + Gumi Omi	15.40±1.31	23.80±1.42	30.60±2.80	37.30±3.44
Peat + Developed OMF for lingonberry	20.70±1.76	30.20±2.58	41.30±3.78	51.40±4.78
LSD_{05}, g: A = 0.66; B = 0.87; AB = 0.56				

Table 5: ANOVA results for morphological and physiological parameters of *Vaccinium vitis-idaea* plants when using fertilizers on peat in the conditions of the Arboretum named after R.I. Schroeder (Moscow, Russia) (n = 30; α = 0.05)

Source	SS	df	MS	F	p-value	F critical
Photosynthesis productivity, mg CO_2 dm^{-2} h^{-1}						
Factor A	2.710275	3	0.903425	17.79490336	5.63E-07	2.90112
Factor B	19.35968	3	6.453225	127.110181	7.41E-18	2.90112
Factors A×B	0.393975	9	0.043775	0.862243014	0.567232	2.188766
Inside	1.6246	32	0.050769			
Total	24.08853	47				
Leaf area of the plant, dm^2						
Factor A	2.0943	3	0.6981	38.37032	1.03E-10	2.90112
Factor B	12.2412	3	4.0804	224.2748	1.47E-21	2.90112
Factors A×B	0.9765	9	0.1085	5.963586	7.03E-05	2.188766
Inside	0.5822	32	0.018194			
Total	15.8942	47				
Total surface of roots, m^2						
Factor A	2419.206	3	806.4019	72.34064	2.39E-14	2.90112
Factor B	1848.201	3	616.0669	55.26608	9.36E-13	2.90112
Factors A×B	135.5269	9	15.05854	1.35087	0.251016	2.188766
Inside	356.7132	32	11.14729			
Total	4759.646	47				
Working adsorbent surface of roots, m^2						
Factor A	1954.521	3	651.5069	60.59891372	2.72E-13	2.90112
Factor B	1435.566	3	478.5219	44.508979	1.59E-11	2.90112
Factors A×B	59.97187	9	6.663542	0.619799118	0.771243	2.188766
Inside	344.0362	32	10.75113			
Total	3794.094	47				
Root weight, g						
Factor A	955.5506	3	318.5169	149.9476	6.4E-19	2.90112
Factor B	1525.386	3	508.4619	239.3677	5.45E-22	2.90112
Factors A×B	18.51188	9	2.056875	0.968311	0.483517	2.188766
Inside	67.974	32	2.124188			
Total	2567.422	47				
Stem weight, g						
Factor A	902.73	3	300.91	15.64287	1.94E-06	2.90112
Factor B	3046.365	3	1015.455	52.78863	1.72E-12	2.90112
Factors A×B	28.605	9	3.178333	0.165226	0.996265	2.188766
Inside	615.5598	32	19.23624			
Total	4593.26	47				
Leaf weight, g						
Factor A	1182.368	3	394.1225	89.70199	1.16E-15	2.90112
Factor B	3588.878	3	1196.293	272.2753	7.55E-23	2.90112
Factors A×B	158.5275	9	17.61417	4.008971	0.001649	2.188766
Inside	140.598	32	4.393688			
Total	5070.371	47				

Yield and Quality of Fruits

Granulated organo-mineral fertilizers have a prolonged (slow) effect and do not require additional feeding during the vegetation period of plants. The main elements are released from the granule with the participation of microflora gradually, are not washed out or evaporated, as is the case with mineral forms of fertilizers. The constant supply of macro- and microelements to plants contributes to increased yields and improved quality indicators of fruits. These indicators of lingonberry fruits when using different types of fertilizers are presented in Table 6, 7.

The use of a developed composition of granular organo-mineral fertilizer made it possible to reliably obtain the highest yield of lingonberry fruits (Kostromskaya Rozovaya – 412.3gm^{-2}, Kostromichka – 578.5gm^{-2}, Rubin – 988.5gm^{-2}, Rossiyanochka – 589.7gm^{-2}), which is significantly higher than in the variants with other fertilizers by 25.8–33.9gm^{-2} (or 6.8–9.0%), 14.4–26.3gm^{-2} (or 2.6–4.8%), 16.3–27.1gm^{-2} (or 1.7–2.8%), and 11.5–22.2gm^{-2} (or 2.0–3.9%), respectively. The content of dry matter and sugar in fruits increased by 1.6–2.0% and 0.8–1.5%, accordingly and amounted to 10.9–13.2% and 9.8–11.6%. The content of vitamin C in the fruits changed slightly and was only 0.4–1.5mg 100 g^{-1} FW lower in the variant without fertilizers than in the variants with other studied fertilizers.

The reliability of the obtained data on the yield and quality of *V. vitis-idaea* products after growing on peat is confirmed by the results of the ANOVA analysis (F statistic value > F critical value; p-value < 0.05) (Table 8).

Nutrient Content in the "Substrate–Plant–Product" System

The dynamics of accumulation of nutrients in the "substrate–plant–product" system when using a developed organo-mineral fertilizer for lingonberry is presented in Table 9.

The content of phosphorus and potassium macronutrients both in the substrate and in *V. vitis-idaea* plants (especially in fruits) when using the developed composition of organo-mineral fertilizer reliably exceeded similar indicators in the variants with Rastvorin for Ericaceae and Gumi Omi, which in turn led to an increase in fruit productivity by 3.4–10.3% and 6.6–13.6%, respectively. Higher content of such important microelements as Ca, Fe, Mg and Mn (118.4, 197.5, 135.2 and 52.7 mg kg^{-1}, respectively) was also noted in fruits. The content of toxic elements in lingonberry fruits under the conditions of our studies after using the developed OMF did not exceed the maximum permissible concentration (MPC) levels in accordance with the Technical Regulations of the Customs Union of the Russian Federation (TR CU 021/2011) "On the safety of food products" (approved by the Decision of the Commission of the Customs Union of the Russian Federation dated December 9, 2011 N 880): As < 0.2mg kg^{-1}; Cd < 0.03mg kg^{-1}; Hg < 0.02mg kg^{-1}; Pb < 0.4mg kg^{-1}.

Table 6: Fruiting characteristics of *Vaccinium vitis-idaea* plants after growing on peat in the conditions of the Arboretum named after R.I. Schroeder (Moscow, Russia)

Fertilizing variation (factor A)	Cultivar (factor B)			
	Kostromskaya Rozovaya	Kostromichka	Rubin	Rossiyanochka
Yield, g m^{-2}				
Peat (control)	369.20±22.10	545.30±42.10	940.50±80.12	554.20±41.60
Peat + Rastvorin for Ericaceae	386.50±24.82	564.10±43.74	972.20±84.35	578.20±44.28
Peat + Gumi Omi	378.40±23.50	552.20±42.80	961.40±83.80	567.50±43.64
Peat + Developed OMF for lingonberry	412.30±29.65	578.50±44.75	988.50±85.65	589.70±45.35
LSD_{05}, gm^{-2}: A = 4.52; B = 1.20; AB = 5,42				
Average fruit weight, g				
Peat (control)	0.45±0.04	0.26±0.02	0.41±0.03	0.41±0.03
Peat + Rastvorin for Ericaceae	0.47±0.04	0.28±0.02	0.43±0.04	0.42±0.04
Peat + Gumi Omi	0.46±0.04	0.27±0.02	0.42±0.04	0.42±0.04
Peat + Developed OMF for lingonberry	0.49±0.05	0.29±0.03	0.44±0.04	0.43±0.04
LSD_{05}, g: A = 0.93; B = 1.66; AB = 1.54				

Table 7: Biochemical composition of *Vaccinium vitis-idaea* fruits after growing on peat in the conditions of the Arboretum named after R.I. Schroeder (Moscow, Russia)

Cultivar	Fertilizing variation	Sugar%	Total acidity %	Dry matter %	Vitamin C mg 100 g^{-1} FW
Kostromskaya Rozovaya	Peat (control)	10.6	1.7	10.6	16.0
	Peat + Rastvorin for Ericaceae	11.0	1.6	11.9	17.5
	Peat + Gumi Omi	10.8	1.6	11.2	16.9
	Peat + Developed OMF for lingonberry	11.5	1.5	12.5	18.2
Kostromichka	Peat (control)	9.1	1.8	9.3	13.7
	Peat + Rastvorin for Ericaceae	9.5	1.7	10.3	14.3
	Peat + Gumi Omi	9.2	1.7	9.7	14.1
	Peat + Developed OMF for lingonberry	9.8	1.6	10.9	15.0
Rubin	Peat (control)	10.1	1.7	11.2	10.6
	Peat + Rastvorin for Ericaceae	10.8	1.6	12.7	11.3
	Peat + Gumi Omi	10.5	1.6	12.4	11.0
	Peat + Developed OMF for lingonberry	11.3	1.5	13.2	12.1
Rossiyanochka	Peat (control)	10.1	1.6	10.7	16.0
	Peat + Rastvorin for Ericaceae	11.2	1.6	11.8	17.5
	Peat + Gumi Omi	10.7	1.6	11.1	16.9
	Peat + Developed OMF for lingonberry	11.6	1.5	12.5	18.2

Table 8: ANOVA results for yield and quality of *Vaccinium vitis-idaea* products after growing on peat in the conditions of the Arboretum named after R.I. Schroeder (Moscow, Russia) (n = 30; α = 0.05)

Source	SS	df	MS	F	p-value	F critical
Yield, gm^{-2}						
Factor A	10280.6	3	3426.867	4.03857219	0.128174	2.90112
Factor B	2157681	3	719227.1	427.8533285	6.86E-26	2.90112
Factors A×B	430.2319	9	47.80354	0.028437338	0.999997	2.188766
Inside	53792.42	32	1681.013			
Total	2222185	47				
Average fruit weight, g						
Factor A	0.005756	3	0.001919	3.790909	0.056291	2.90112
Factor B	0.254006	3	0.084669	123.1545	1.18E-17	2.90112
Factors A×B	0.000469	9	5.21E-05	0.075758	0.999833	2.188766
Inside	0.022	32	0.000688			
Total	0.282231	47				

Table 9: The content of macro- and microelements in the substrate, plants, and fruits of *V. vitis-idaea* after growing on peat in the conditions of the Arboretum named after R.I. Schroeder (Moscow, Russia)

Elements, mg kg^{-1}	Variation			
	Peat (control)	Peat + Rastvorin for Ericaceae	Peat + Gumi Omi	Peat + Developed OMF for lingonberry
In the substrate				
B	1.45±0.13	2.54±0.18	2.37±0.17	2.81±0.18
Ca	2923.00±90.42	3204.00±119.21	3163.00±124.15	3382.00±131.42
Cu	0.52±0.04	1.28±0.09	1.15±0.11	1.35±0.14
Fe	35.70±2.71	44.25±3.16	39.70±3.16	61.50±5.95
I	1.35±0.15	1.18±0.13	2.15±0.12	2.53±0.12
K	703.00±52.92	456.00±39.82	425.00±31.67	842.00±60.45
Mg	696.00±61.53	634.00±57.12	589.00±49.13	713.00±49.57
Mn	73.00±6.92	194.00±14.97	137.00±8.92	325.00±17.05
P	226.00±13.47	328.00±27.73	195.00±10.55	403.00±28.13
In plants (on average by cultivars)				
B	55.20±3.85	75.10±5.23	68.40±6.05	90.80±7.83
Ca	4 103.00±122.13	6 135.00±241.18	5 896.00±195.67	7 225.0±257.15
Cu	5.41±0.27	6.85±0.32	6.24±0.33	8.35±0.56
Fe	32.90±2.25	50.20±3.49	43.10±3.19	51.40±3.18
I	1.15±0.08	2.01±0.12	1.68±0.13	2.15±0.11
K	15 332.00±650.18	17 450.0±697.55	16 674.0±621.25	18 457.0±723.15
Mg	2 185.00±67.42	4 123.0±153.12	3 574.0±136.23	4 635.0±157.83
Mn	1 543.00±81.24	1 985.0±85.25	1 963.0±91.73	2 164.0±106.67
P	2 125.00±93.34	2 923.0±97.39	2 632.0±108.15	3 625.0±115.43
In fruits (on average by cultivars)				
B	0.15±0.01	0.19±0.02	0.17±0.01	0.20±0.02
Ca	96.30±7.35	112.50±9.95	109.10±5.77	118.40±6.12
Cu	17.52±1.06	21.26±1.17	20.50±2.97	22.70±2.35
Fe	185.10±12.55	193.80±15.12	190.30±13.48	197.50±14.85
I	0.95±0.02	1.12±0.07	1.18±0.07	1.30±0.08
K	610.50±53.17	704.60±65.75	650.70±49.14	693.50±58.42
Mg	22.40±1.14	38.55±2.61	30.06±2.19	52.70±3.25
Mn	83.70±4.85	116.31±8.73	98.50±6.64	135.20±11.42
P	44.15±3.95	50.12±4.05	47.90±3.78	52.81±4.69

DISCUSSION

Ongoing field trials aim to refine open-field cultivation of lingonberry by optimizing fertilizer regimes, improving other technological elements, and ensuring timely crop care. Our findings are comparable in effectiveness to established mineral-fertilizer approaches for enhancing nutrition in *V. vitis-idaea* (Chester & McGraw, 1983; Scibisz

& Pliszka, 1985; Eriksson & Raunistola, 1993; Levula et al., 2000; Taulavuori et al., 2001; Makhovik, 2005; Saario, 2005), underscoring the promise of their application for lingonberry cultivation across current production regions, including Western Europe and Belarus. The results of some studies on the use of only mineral fertilizers in Russia (the European part, the Urals, Siberia) (Zaparanyuk, 1984; Tyak et al., 1998; Gorbunov, 2016) show a positive effect of their use on the yield of lingonberries, while the instability of this indicator can be explained by the fact that a complex of other factors (agrochemical parameters of the soil, the formation of a favorable microbiome, the accumulation of nutrients in plants) is not taken into account (Karlsons et al., 2021).

In turn, complex organo-mineral fertilizers when growing berry plants are able to adsorb and retain nutrients by increasing the total surface area. The porous structure of organo-mineral fertilizers helps to increase their contact interaction with the root system of plants. The high absorption capacity of peat granules and moisture retention prevent the possibility of washing out important nutrients. The use of organo-mineral fertilizers also helps to reduce soil salinization, unjustified mineralization of organic matter, increase plant productivity and improve the biological environment as a whole. At the same time, mineral and organo-mineral fertilizers available on the Russian market for growing plants from the Ericaceae family can often be species specific and are not suitable for providing nutrition to specific species, including lingonberry (Sharifi et al., 2024).

Today there are very few studies on the use of complex organo-mineral fertilizers in the cultivation of lingonberries (Bozhiday, 2019; Karlsons et al., 2021; Sharifi et al., 2024). Studies on the use of complex organo-mineral fertilizer of prolonged action Basacote 6M Plus (COMPO GmbH & Co, Germany) in growing lingonberries (Bozhiday, 2019) showed positive results, but the effect of fertilizer application has so far been studied only in closed ground conditions, during micro plant adaptation under *ex vitro* conditions. However, the conditions of closed ground can differ greatly from the conditions of open ground, taking into account the specific agroclimatic characteristics of the Central part of the Non-Chernozem zone of Russia, and do not allow for a full comparison with the results we obtained.

Experience with the use of the complex fertilizer NovaTec® Classic 12-8-16(+3+TE) (COMPO GmbH & Co, Germany) with microelements on peat soils (pH 3.47) in the conditions of Latvia showed its ability to stimulate the growth reaction of lingonberry (Runo Bielawskie cultivar) plants, increase the volume of formed rhizomes, and additional 3-fold foliar feeding with Omex Bio 20 fertilizer chelate (Omex Agrifluids Ltd., UK) ensures adequate concentrations of microelements in plant leaves (Karlsons et al., 2021). In a study using the universal growing medium PRO-MIX BX, which includes *Sphagnum* L. moss, perlite, limestone, vermiculite, a wetting agent, and mycorrhizal fungi (*Glomus intraradices*) (Sharifi et al., 2024), the authors noted an improvement in the agrochemical characteristics of the soil, morphometric and physiological parameters of lingonberry plants, but this substrate was used in the soil and climatic conditions of Canada (North America).

Thus, the proposed researches demonstrate improvement of soil characteristics and increase in yield of lingonberry when using complex organo-mineral fertilizers compared to classic mineral fertilizers (NPK), which is consistent with the results of our research. At the same time, strong differences in agroclimatic conditions and peat soils typical for the Non-Chernozem zone of Russia contain mycorrhiza, organic matter, have natural acidity and active mobile forms of N, P, K, which are optimal conditions for lingonberry cultivation. In this regard, it is unacceptable to use fertilization systems used in Western Europe and North America, where lingonberry is grown on mineral soils using artificial acidification and high concentrations of mineral fertilizers. In turn, the developed organo-mineral fertilizer for lingonberry on single site in the agroclimatic conditions of Moscow as a part of the Non-Chernozem zone of Russia allows for improved agrochemical characteristics of the soil, morphological and physiological parameters of lingonberry plants for Russian selection cultivars, high yields, optimal composition of micro- and macroelements in the soil, in lingonberry plants and fruits, while avoiding additional fertilizing and the costs of its implementation.

At the same time, reported benefits of developed composition OMF combines mineral NPK+TE with a vermicompost bacterial consortium could arise from: 1) improved peat pH/CEC and moisture retention; 2) added organic matter; 3) micronutrients (notably Cu 0.4%, and Fe 0.5%); and/or 4) microbial activity. Current results of the dependence of features based on the results of correlation analysis do not yet disentangle these effects. In this regard, further research is needed. However, this does not detract from the apparent practical effectiveness of the development.

Also it is necessary to remember about compliance with safety standards and regulatory requirements for concentrations of microelements and any restrictions when growing berry crops using fertilizers.

Conclusion

In summary, the use of a developed composition of organo-mineral fertilizer in the cultivation of *Vaccinium vitis-idaea* contributed to the improvement of the agrochemical and microbiological properties of the soil, and, as a consequence, the root nutrition of plants due to the provision of the necessary macro- and microelements. At the same time, an improvement in the biometric and physiological characteristics of lingonberry plants, as well as an increase in the yield and quality of the resulting berry products, was noted. The results obtained allow us to recommend the use of this organo-mineral fertilizer with composition (NPK 8:8:8, Cu 0.4%, Fe 0.5%, Zn 0.2% + vermicompost containing spore forms of bacteria with high biological activity) in the dose of 55.6 g m^{-2} on high-moor peat substrate in the cultivation of lingonberries of Russian in the conditions of Moscow region as a part of Non-Chernozem Zone of Russia.

However, further research is needed to test this fertilizer at multiple sites (include factorial designs, and microbial vs. chemical disentanglement) for more large-scale recommendations for the territory of the Non-Chernozem Zone of Russia, including industrial scale on plantations. In the future, it is also necessary to test this composition or create a new modified composition of the fertilizer for the cultivation of other cultivars of lingonberry and other berry crops capable of growing on peat substrates (cranberries, blueberries, arctic bramble, cloudberry, etc.).

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