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EFFECT OF MICROBIOLOGICALLY ENRICHED FERTILIZERS ON THE VEGETATIVE GROWTH OF STRAWBERRY PLANTS UNDER FIELD CONDITIONS IN THE FIRST YEAR OF PLANTATION

Summary

The experiment was established in the spring of 2018 in the Experimental Orchard of the Research Institute of Horticulture in Dąbrowice (Central Poland). It was conducted on strawberry plants of the cultivar 'Marmolada'. The experiment included the following experimental combinations: 1. Control – no fertilizer; 2. Standard NPK fertilization (control); 3. Control with fungi only (Aspergillus niger and Purpureocillium lilacinum); 4. Control with bacteria only (Bacillus sp., Bacillus amyloliquefaciens and Paenibacillus polymyxa); 5. Standard NPK + fungi; 6. Standard NPK + bacteria; 7. Polifoska 6 innovative fertilizer 100% + bacteria; 8. Urea 100% + fungi; 9. Polifoska 6 100% + bacteria; 10. Super Fos Dar 40 innovative fertilizer 100% + bacteria; 11. Urea 60% + fungi; 12. Polifoska 6 60% + bacteria; 13. Super Fos Dar 40 60% + bacteria; 14. Polifoska 6 100% without bacteria; 15. Urea 100% without fungi; 16. Super Fos Dar 40 100% without bacteria. In the middle of the summer, the surface area of the leaves, the intensity of the green colour of the leaves, and the concentration of macro- and microelements in them were measured. In the autumn, the runners were cut off, and their number, fresh weight and length, and the number and fresh weight of the runner plants were determined. Urea, in combination with fungi, had the greatest influence on the fresh weight of the leaves and their surface area. The applied fertilization treatments did not cause any changes in the intensity of the green colour of the leaves. Under the influence of the applied microbiologically enriched fertilizers and the microorganisms added to the soil on their own, the mineral composition of the leaves changed. In the groups of macro- and microelements, the fertilizers Super Fos Dar 40 and Polifoska 6 enriched with bacteria caused an increase in the levels of the elements analyzed. Urea enriched with strains of filamentous fungi produced a similar effect. In the first year of running the plantation, the largest number and weight of runners were formed by the strawberry plants fertilized with a full dose of Urea. The use of the bacterial mixture had a very beneficial influence on the number and length of runners and the quality of runner plants. In 2018, fruiting was not evaluated because all the inflorescences were removed in order to intensify the vegetative growth of the plants.
Keywords: *fertilization, beneficial microorganisms, plant growth, Fragaria × ananassa*

WPŁYW NAWOZÓW WZBOGACONYCH MIKROBIOLOGICZNIE NA WZROST WEGETATYWNY TRUSKAWKI W WARUNKACH POLOWYCH W PIERWSZYM ROKU PROWADZENIA PLANTACJI

Streszczenie

Doświadczenie założono wiosną 2018 roku w Sadzie Doświadczalnym Instytutu Ogrodnictwa w Dąbrowicach, a przeprowadzono je na roślinach truskawki odmiany Marmolada w następujących kombinacjach: 1. Kontrola – bez nawożenia; 2. Nawożenie standardowe NPK (kontrola); 3. Kontrola tylko z grzybami (Aspergillus niger i Purpureocillium lilacinum); 4. Kontrola tylko z bakteriami (Bacillus sp., Bacillus amyloliquefaciens i Paenibacillus polymyxa); 5. Nawożenie standardowe NPK + grzyby; 6. Nawożenie standardowe NPK + bakterie; 7. Polifoska 6, 100% - innowacyjny nawóz+ bakterie; 8. Mocznik 100% + grzyby; 9. Polifoska 6 + bakterie; 10. Super Fos Dar 40, 100% - innowacyjny nawóz + bakterie; 11. Mocznik 60%+ grzyby; 12. Polifoska 6, 60% + bakterie; 13. Super Fos Dar 40, 60% + bakterie; 14. Polifoska 6, 100% bez bakterii; 15. Mocznik 100% bez grzybów; 16. Super Fos Dar 40, 100% bez bakterii. W połowie lata mierzono powierzchnię liści, natężenie zielonej barwy liści oraz zawartość w nich makro- i mikroelementów. Jesienią odcinano rozłogi, określano ich liczbę, świeżą masę, długość, liczbę oraz świeżą masę sadzonek rozłogowych. Mocznik w połączeniu z grzybami w największym stopniu wpłynął stymulująco na świeżą masę liści i pole ich powierzchni. Zastosowane kombinacje nawożenia nie powodowały zmian w intensywności zielonej barwy liści truskawki. Pod wpływem zastosowanych nawozów wzbogaconych mikrobiologicznie oraz samych mikroorganizmów dodawanych do gleby zmieniał się skład mineralny liści. W grupie makro- i mikroelementów nawozy Super Fos Dar 40 i Polifoska 6 wzbogacone bakteriami spowodował wzrost poziomu badanych pierwiastków. Podobne działanie miał mocznik wzbogacony szczepami grzybów strzępkowych. W pierwszym roku prowadzenia plantacji największą liczbę i masę rozłogów wytworzyły rośliny truskawki nawożone pełną dawką mocznika. Bardzo korzystnie na liczbę i długość rozłogów oraz jakość sadzonek rozłogowych wpłynęło zastosowanie mieszaniny bakterii. W 2018 roku owocowania nie oceniano, ponieważ wszystkie kwiatostany zostały usunięte w celu zintensyfikowania wzrostu wegetatywnego roślin.
Słowa kluczowe*: nawożenie, pożyteczne mikroorganizmy, wzrost roślin, Fragaria × ananassa*

1. Introduction

In recent years, farmers' awareness of the need to limit the use of chemicals in crop production has been growing [1, 4, 33]. It is related, *inter alia*, to the development of alternative biological substances, incorporating e.g. beneficial microorganisms, in the mineral nutrition of plants and stimulation of their growth and development. They are also used to protect plants against diseases and pests, and to improve soil quality [12, 15, 28].

A high level of mineral fertilization does not only increase production costs but is also a potential cause of eutrophication and pollution of the soil environment, drinking water and air [3]. One of the proposed solutions in the area of environmental and human health protection is the implementation of natural plant cultivation technologies and plant fertilization through the use of bio-fertilizers [6, 9, 10, 15, 16, 22, 26, 27, 32]. Products of this type exert a positive influence on the growth and yield of arable crops, as well as on soil fauna, including the development of arbuscular mycorrhizal fungi and filamentous fungi [23, 24, 35]. The use of fertilizers enriched with beneficial strains of bacteria and fungi is believed to increase their effectiveness in the cultivation of plants [5, 7, 9, 10, 15]. Thanks to microorganisms, the physiological condition of crop plants is also strengthened, intensification of growth and yielding occurs, and plant resistance to environmental and biotic stresses increases [8, 36, 37, 38].

The availability of traditional organic fertilizers, such as manure and composts of plant origin, is becoming increasingly limited [1, 26]. Many authors believe that one of the innovative solutions in modern agriculture is the enrichment of organic fertilizers, composts and liquid plant growth promoters with consortia of beneficial microorganisms [20, 29, 34]. The presence of native filamentous and mycorrhizal soil fungi and beneficial strains of bacteria in new bioproducts introduced into the market ensures their better adaptation and survival under favourable environmental conditions [18, 25, 30, 33].

Modern agriculture is still looking for environmentally friendly fertilizers, mainly for organic farms [1, 26]. The availability of traditional means of agricultural production, such as farmyard manure and composts, is being reduced. One of the innovative solutions is the enrichment of organic fertilizers, composts and liquid plant growth promoters with consortia of beneficial microorganisms [20, 29, 34]. The presence of native filamentous and mycorrhizal fungi and beneficial bacterial strains in new bioproducts, introduced into the market, ensures their better adaptation and survival under favourable environmental conditions, which is an extremely important factor in their long-term impact on plants [30]. Filamentous fungi and arbuscular mycorrhizal fungi (AMF), and beneficial bacteria responsible for the growth and physiological condition of roots can improve the mineral nutrition of plants, and their use in agriculture can lead to a significant reduction in the use of chemicals commonly considered harmful to the environment [9, 17, 18, 19, 33].

The structure of the root system, and in particular its morphological characteristics, is also modified by various abiotic and biotic factors [14]. Numerous research studies have proved that the colonization of the root system by AMF fungi can change its morphological structure, including the size of the roots, their topographical layout, as well as their surface area and volume [9, 10, 21]. The presence of beneficial filamentous fungi and AMF in the soil is believed to mitigate the impact of adverse environmental factors acting on the plant [33, 36]. In the scientific literature there are results of research on the positive impact of bioproducts and those enriched with soil microorganisms on the size of the root system as well as the growth and yielding of crop plants, but they do not yet include many of those of high economic importance in commercial production.

The aim of the study was to assess the effects of fertilization with innovative fertilizers enriched with strains of beneficial bacteria and filamentous fungi on the growth of strawberry plants in the first year after their application. In the following years, the subject of research will be the yielding of the plants and the quality of the fruit obtained depending on the fertilization treatments used.

Research hypothesis

Innovative microbiologically enriched fertilizers favourably affect the growth and development of strawberry plants relative to the control treatment without fertilization and NPK fertilization.

2. Materials and methods

The experiment was established in the spring of 2018 in the Experimental Orchard of the Research Institute of Horticulture in Dąbrowice (Central Poland, 51° 91 41 88 N, 20° 11 13 89 E, 145 m a.s.l.) and will run for three consecutive years. The subject of the research are strawberry plants of the cultivar 'Marmolada' (synonym 'Onebor'). Frigo A+ plantlets (15-18 mm) were planted in early May on a podzolic soil underlaid by sandy loam, rated as soil quality class 3b. The soil pH was slightly acidic at pH 6.2 (in KCl), and the average humus content of the soil was 1.2%. The levels of minerals in the soil, including macroelements, was as follows: P – 7.5; K – 12.4; Mg – 5.8 mg/100 g, and microelements: B – 2.4; Cu – 4.8; Fe – 862; Mn – 75.5; Na – 4.35; Zn – 3.7 mg/1000 g. Thermal and humidity conditions: the average temperature in the individual months of the season was – April 13°C, May 17°C, June 22°C, July 25°C, August 24°C, September 18°C, October 10°C; the average relative humidity in those months was – April 60%, May 70%, June 60%, July 75%, August 60%, September 55%, October 60% (https://meteoblue.com/pl/pogoda/).

On a single plot of 3 m in length, 12 plants were planted. The distances between the plants in a row were 0.25 m and between the rows 1 m. The experiment was established in a random block design in four replications. Each experimental combination was represented by 48 plants.

The experiment included the following experimental combinations:

1. Control (no treatment) – unfertilized podzolic soil (mineral composition given above).
2. Control – standard NPK soil fertilization – before planting, 12 g of Super Fos Dar 40 granulated fertilizer, 50 g of potassium salt and 35 g of Urea were used on an individual plot. Urea in the amount of 12 g per plot was also applied in mid-summer.
3. Control (no fertilization) – beneficial soil fungi in the amount of 5.25 g per plot were applied along the rows immediately after planting the plants, thoroughly mixing them with the soil. The mixture of beneficial soil fungi contained two species: *Aspergillus niger* and *Purpureocillium lilacinum*.

4. Control (no fertilization) – with beneficial bacteria. For each plot, 3.83 g was applied along the rows immediately after planting the plants, thoroughly mixing them with the soil. The mixture of beneficial bacteria contained three strains of *Bacillus* (*Bacillus* sp., *Bacillus amyloliquefaciens* and *Paenibacillus polymyxa*).
5. Control standard NPK soil fertilization as in point 2 with the beneficial soil fungi listed in point 3.
6. Control standard NPK soil fertilization as in point 2 and the beneficial bacteria applied to the soil as in point 4.
7. Polifoska 6 in a 100% dose, including three strains of bacteria of the genus *Bacillus*, which had been incorporated into the fertilizer during the formation of granules. For each plot, Polifoska 6 was used in the amount of 26 g before planting; Urea, in the amount of 30 g was applied once before planting, and the second time in the amount of 20 g in mid-summer; potassium salt was used in the amount of 33 g.
8. Urea in a 100% dose enriched with strains of filamentous fungi of the species and quantitative composition as in point 3. For each plot before planting, 50 g of potassium salt, 35 g of Urea, and 12 g of Super Fos Dar 40 fertilizer were used. Urea in the amount of 20 g was also applied in mid-summer.
9. Polifoska 6 in a 100% dose enriched with three strains of *Bacillus* bacteria in the amount and species composition as in point 4. Before planting the plants, 26 g of Polifoska 6, 33 g of potassium salt, and 30 g of Urea were used per one plot. Urea in the amount of 20 g was also used in mid-summer.
10. Super Fos Dar 40 in a 100% dose enriched with three strains of *Bacillus* bacteria was applied in the amount of 3.83 g per plot. In addition, before planting the plants, the soil was fertilized with 50 g of potassium salt, 12 g of Super Fos Dar 40 fertilizer, and Urea – 35 g before planting and 20 g in mid-summer.
11. Urea in a 60% dose enriched with strains of filamentous fungi of the species and quantitative composition as in point 3. For each plot before planting the plants, 30 g of potassium salt, 20 g of Urea and 7 g of Super Fos Dar 40 were used. Urea in the amount of 12 g was also applied in mid-summer.
12. Polifoska 6 in a 60% dose enriched with three strains of bacteria of the genus *Bacillus* was used in the same way as in point 9. Before planting the plants, 14 g of Polifoska 6, 30 g of potassium salt and 18 g of urea were used for each plot. Urea in the amount of 12 g was also used in mid-summer.
13. Super Fos Dar 40 in a 60% dose enriched with three *Bacillus* bacterial strains was used in the same way as in point 12. Before planting, 7 g of Super Fos Dar 40, 30 g of potassium salt and 20 g of urea were used per plot. Urea in the amount of 12 g was also used in mid-summer.
14. Polifoska 6 in a 100% dose without beneficial bacteria was used in the amount of 26 g before planting. In addition, potassium salt was applied in the amount of 33 g and Urea in the amount of 30 g before planting and 20 g in mid-summer.
15. Urea in a 100% dose without filamentous fungi. Before planting the plants, 50 g of potassium salt, 35 g of Urea and 12 g of Super Fos Dar 40 fertilizer were also applied. Urea in the amount of 20 g was also used in mid-summer.
16. Super Fos Dar 40 in a 100% dose without bacteria. Before planting the plants, the plots were fertilized with 50 g of potassium salt, 12 g of Super Fos Dar 40 and 35 g of Urea. Urea (20 g) was also used in mid-summer.

During the growing season, the weeds on the experimental plots were removed by hand. During periods of water deficit, the plantation was drip-irrigated in accordance with the indications of tensiometers. In the first year after planting, the inflorescences were systematically removed so that the fruit would not inhibit the growth of the young plants. The influence of the microbiologically enriched fertilizers and microorganisms applied to the soil on their own on the growth of strawberry plants was assessed on the basis of the weight and size of the leaves, intensity of their green colour and amounts of minerals in them, and the intensity of the formation of runners and morphological characteristics of the roots.

2.1. Measurements and observations made

Leaves

1. The surface area of 5 leaves collected from two plants of each replication was measured using an EPSON EXPRESSION 10000 XL scanner. The surface area was expressed in cm^2.
2. The intensity of the green colour of the leaves was determined with a SPAD 502 meter using a sample of 5 leaves taken from two plants in each replication.
3. The concentration of minerals was determined on the basis of a sample of 25 leaves taken from plants from each plot. The leaves, together with petioles, were collected for analysis in mid-August.

Runners were cut off from the plants in the second half of September and the following was determined:

1. Number of runners in a sample taken from 5 plants from each plot.
2. Fresh weight of runners (g).
3. Length of runners (cm).
4. Number of runner plants.
5. Fresh weight of runner plants (g).

2.2. Analysis of root growth characteristics

The root system of the strawberry plants (of one plant from each replication) was placed on a sieve and gently rinsed with water to clean off the soil. After drying, the roots were weighed and then scanned using the EPSON EXPRESSION 10000 XL root scanner. The growth characteristics of the roots (length, surface area, diameter, volume and number of root tips) were determined using the WinRhizo software [2].

Based on the measurements made, the following was determined:

1. Fresh weight of roots (g).
2. Dry weight of roots (g).
3. Length of roots (mm).
4. Surface area of roots (cm^2).
5. Diameter of roots (mm).
6. Volume of roots (cm^3).
7. Number of root tips.

2.3. Analysis of macro- and microelements

The concentrations of macro- and microelements in leaf tissue were analyzed by the Chemical Laboratory of the Research Institute of Horticulture, Skierniewice, Poland. For the determination of available forms of phosphorus and potassium in a mineral soil, the Egner-Riehm method was used. The method consists in extracting phosphorus and potassium compounds from the soil by means of calcium lactate. For the determination of available forms of magnesium in a mineral soil, the Schachtschabel method was used. For the determination of available forms of microelements in soil, the method of extraction in 1M HCl was used. Determination of the mineral content of plant material was done in the process of mineralization (combustion). Wet combustion of vegetable matter consists in complete oxidation with liquid oxidants such as concentrated sulphuric acid, nitric acid or perchloric acid, used individually or in various combinations and proportions. For the determination of mineral content of the solutions obtained by the analytical methods mentioned above, measurements were carried out using the technique of atomic emission spectrometry with excitation in inductively coupled plasma (ICP-OES). Total nitrogen content in plant material was determined by the conductometric method according to Dumas, using a TruSpec CNS analyzer.

2.4. Statistical analysis

The results were statistically analyzed using one-way analysis of variance with the Tukey test, $\alpha = 0.05$, using the statistical program Statistica 13.1. Data not significantly different from each other were marked with the same letters.

2.5. Characteristics of the fertilizers Super Fos Dar 40, Polifoska 6 and Urea

Super Fos Dar 40 belongs to the group of the most concentrated phosphate fertilizers. It contains 40% P_2O_5 – phosphorus pentoxide soluble in mineral acids; 25% P_2O_5 soluble in a neutral citrate solution and water; 10% CaO – calcium oxide soluble in water, and microelements (Co, Cu, Fe, Mn, Zn), which are a valuable addition, derived from natural phosphorites, that improves the assimilation of other ingredients.

Polifoska 6 is a granulated fertilizer that contains 6% nitrogen (N) in ammonium form, 20% phosphorus (P_2O_5), 30% potassium (K_2O) in the form of a potassium salt, and 7% sulphur trioxide (SO_3) soluble in water in the form of sulphate.

Urea contains 46% nitrogen (N) in amide form.

3. Results

Urea in combination with fungi (treatment 8) had the greatest impact on the increase in the fresh weight of leaves and their surface area. The leaves of plants treated with Polifoska 6 with bacterial strains (treatment 12) had the smallest mass and surface area; however, compared to the control combinations, those differences were not significant. The applied fertilization methods did not cause any changes in the intensity of the green colour of strawberry leaves (Table 1).

Under the influence of the applied microbiologically enriched fertilizers and the microorganisms added to the soil on their own, the mineral composition of the leaves changed. In the group of macroelements, Super Fos Dar 40 enriched with bacteria (treatment 10) caused an increase in the level of nitrogen (N) in strawberry leaves compared to the control combination without fertilization. Mineral fertilization of strawberry plants with NPK alone (treatment 2) and NPK enriched with bacteria (treatment 6) promoted an increase in the level of phosphorus (P) in the leaves. Urea enriched with filamentous fungi (treatment 8) had a similar effect. Under the influence of NPK fertilization enriched with fungi (treatment 5), the level of calcium (Ca) in strawberry leaves increased markedly. The applied fertilization combinations had no effect on the potassium content (K) of the leaves (Table 2).

Table 1. Effect of microbiologically enriched mineral fertilizers on the size and intensity of the green colour of the leaves of 'Marmolada' strawberry plants (IO Experimental Orchard, Dąbrowice, 2018)

Tab. 1. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na wielkość i natężenie zielonej barwy liści roślin truskawki odmiany 'Marmolada' (Sad Doświadczalny IO, Dąbrowice, 2018 r.)

No.	Treatment	Fresh weight of 5 leaves [g]	Surface area of 5 leaves [cm^2]	Leaf green colour intensity [SPAD]
1.	Control – no fertilization (fertilizer combination)	21.0 ab*	1197.1 a	41.1 a
2.	Control NPK (fertilizer combination)	21.2 ab	1208.7 ab	40.7 a
3.	Control – no fertilization + strains of filamentous fungi (fertilizer combination)	23.8 ab	1319.7 ab	40.9 a
4.	Control – no fertilization + bacterial strains (fertilizer combination)	22.3 ab	1186.8 a	40.0 a
5.	Control NPK + strains of filamentous fungi (fertilizer combination)	24.8 ab	1367.4 ab	41.8 a
6.	Control NPK + bacterial strains (fertilizer combination)	22.7 ab	1321.3 ab	40.5 a
7.	Polifoska 6 100% + bacterial strains	21.8 ab	1244.9 ab	41.9 a
8.	Urea 100% + strains of filamentous fungi	25.6 b	1471. 1 b	40.9 a
9.	Polifoska 6 100% + bacterial strains	20.2 a	1123.1 a	42.4 a
10.	Super Fos Dar 40 100% + bacterial strains	23.2 ab	1368.2 ab	41.0 a
11.	Urea 60% + strains of filamentous fungi	20.4 a	1241.0 ab	40.1 a
12.	Polifoska 6 60% + bacterial strains	20.3 a	1113.4 a	40.4 a
13.	Super Fos Dar 40 60% + bacterial strains	22.8 ab	1320.1 ab	41.1 a
14.	Polifoska 6 100%	21.4 ab	1202.0 ab	40.1 a
15.	Urea 100%	22.7 ab	1351.0 ab	42.9 a
16.	Super Fos Dar 40 100%	22.7 ab	1252.8 ab	41.1 a

* Means marked with the same letters in a column do not differ significantly at $\alpha = 0.05$.

Source: own study / Źródło: opracowanie własne

Table 2. Effect of microbiologically enriched mineral fertilizers on the concentration of macroelements in the leaves of 'Marmolada' strawberry plants (IO Experimental Orchard, Dąbrowice, 2018)

Tab. 2. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na zawartość makroelementów w liściach roślin truskawki odmiany 'Marmolada' (Sad Doświadczalny IO, Dąbrowice, 2018 r.)

No.	Treatment	N	P	K	Mg	Ca
		%				
1.	Control – no fertilization (fertilizer combination)	1.83 de*	0.40 c-e	1.76 a	0.26 ab	1.31 a
2.	Control NPK (fertilizer combination)	1.92 h	0.47 g	2.00 a	0.26 ab	1.41 c
3.	Control – no fertilization + strains of filamentous fungi (fertilizer combination)	1.81 b-d	0.44 fg	2.01 a	0.26 ab	1.49 de
4.	Control – no fertilization + bacterial strains (fertilizer combination)	1.79 bc	0.45 fg	2.03 a	0.25 ab	1.36 b
5.	Control NPK + strains of filamentous fungi (fertilizer combination)	1.73 a	0.35 ab	2.06 a	0.26 ab	1.56 h
6.	Control NPK + bacterial strains (fertilizer combination)	1.87 fg	0.47 g	2.10 a	0.26 ab	1.51 e-g
7.	Polifoska 6 100% + bacterial strains	1.86 e-g	0.39 cd	2.12 a	0.25 ab	1.52 e-g
8.	Urea 100% + strains of filamentous fungi	1.83 de	0.39 cd	2.11 a	0.27 b	1.54 gh
9.	Polifoska 6 100% + bacterial strains	1.88 g	0.38 bc	2.16 a	0.26 ab	1.47 d
10.	Super Fos Dar 40 100% + bacterial strains	1.94 h	0.34 a	1.90 a	0.24 ab	1.29 a
11.	Urea 60% + strains of filamentous fungi	1.84 d-f	0.47 g	2.15 a	0.25 ab	1.49 de
12.	Polifoska 6 60% + bacterial strains	1.78 b	0.43 gf	2.05 a	0.24 ab	1.43 c
13.	Super Fos Dar 40 60% + bacterial strains	1.83 de	0.39 cd	2.00 a	0.27 b	1.53 f-h
14.	Polifoska 6 100%	1.87 fg	0.43 ef	2.03 a	0.26 ab	1.42 c
15.	Urea 100%	1.87 fg	0.35 ab	2.04 a	0.23 a	1.28 a
16.	Super Fos Dar 40 100%	1.82 cd	0.42 d-f	2.12 a	0.27 b	1.50 d-f

* Means marked with the same letters in a column do not differ significantly at α = 0.05.

Source: own study / Źródło: opracowanie własne

Based on the analysis of the level of microelements in strawberry leaves, it should be stated that the experimental combinations did not significantly modify the concentrations of boron (B) and copper (Cu). However, some differences appeared in the levels of iron (Fe), manganese (Mn) and zinc (Zn). The fertilizer Polifoska 6 in a 60% dose enriched with bacteria (treatment 12) caused an increase in the level of iron, and in a 100% dose enriched with bacteria (treatment 7) contributed to an increase in the level of manganese. In the combinations where Super Fos Dar was applied in a 60% dose with bacterial strains (treatment 13) and a full dose of Polifoska 6 without bacteria (treatment 14) there was a higher concentration of zinc in the leaves than in the combination with Polifoska 6 in a 100% dose with bacteria (treatment 9) (Table 3).

Table 3. Effect of microbiologically enriched mineral fertilizers on the concentration of microelements in the leaves of 'Marmolada' strawberry plants (IO Experimental Orchard, Dąbrowice, 2018)

Tab. 3. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na zawartość mikroelementów w liściach roślin truskawki odmiany 'Marmolada' (Sad Doświadczalny IO, Dąbrowice, 2018 r.)

No.	Treatment	B	Cu	Fe	Mn	Zn
		mg/kg				
1.	Control – no fertilization (fertilizer combination)	35.0 a*	5.09 a	142 a	62.2 c	19.7 a-c
2.	Control NPK (fertilizer combination)	33.5 a	4.99 a	177 g	54.7 a	18.6 a-c
3.	Control – no fertilization + strains of filamentous fungi (fertilizer combination)	40.4 a	5.29 a	167 e	66.8 de	19.7 a-c
4.	Control – no fertilization + bacterial strains (fertilizer combination)	35.4 a	5.10 a	173 f	62.2 c	19.4 a-c
5.	Control NPK + strains of filamentous fungi (fertilizer combination)	36.0 a	4.85 a	156 d	72.9 g	19.3 a-c
6.	Control NPK + bacterial strains (fertilizer combination)	34.9 a	5.03 a	165 e	64.6 cd	18.3 a-c
7.	Polifoska 6 100% + bacterial strains	35.9 a	4.85 a	188 h	74.5 g	19.1 a-c
8.	Urea 100% + strains of filamentous fungi	35.4 a	4.78 a	179 g	62.2 c	17.3 ab
9.	Polifoska 6 100% + bacterial strains	31.8 a	5.17 a	172 f	55.9 ab	16.8 a
10.	Super Fos Dar 40 100% + bacterial strains	30.9 a	4.99 a	150 c	58.1 b	18.8 a-c
11.	Urea 60% + strains of filamentous fungi	35.4 a	5.24 a	186 h	62.5 c	18.1 a-c
12.	Polifoska 6 60% + bacterial strains	33.3 a	4.84 a	210 i	54.0 a	19.1 a-c
13.	Super Fos Dar 40 60% + bacterial strains	34.6 a	5.06 a	177 g	66.3 de	20.6 c
14.	Polifoska 6 100%	35.2 a	4.89 a	157 d	69.3 ef	21.0 c
15.	Urea 100%	34.7 a	5.03 a	146 b	69.0 ef	18.3 a-c
16.	Super Fos Dar 40 100%	34.8 a	5.15 a	188 h	71.6 fg	19.9 bc

* Means marked with the same letters in a column do not differ significantly at α = 0.05.

Source: own study / Źródło: opracowanie własne

The tests carried out in the first year of running the plantation on runners taken from 5 plants in each replication showed that the largest number and weight of runners were formed by strawberry plants fertilized with a full dose of Urea with no filamentous fungi (treatment 15). The introduction of a mixture of bacterial strains into the soil (not fed with fertilizers) (treatment 4) had a beneficial effect on the number and length of runners and the quality of runner plants. The smallest number of runner plants and their lowest fresh weight were produced by the plants treated with a full dose of Polifoska 6 enriched with bacterial strains (treatment 14), but in comparison with the control combinations those differences were not statistically significant (Table 4).

Already in the first year of the study, the influence of the applied fertilization combinations on the quality of the root system was evident. The plants fertilized conventionally with NPK (treatment 2), those treated with a full dose of Polifoska 6 enriched with bacterial strains (treatment 12), and those fertilized with a full dose of Super Fos Dar 40 (treatment 16) produced roots with a higher weight than the plants treated with Urea in a 60% dose with strains of filamentous fungi (treatment 11) and those fertilized only with a full dose of Urea without filamentous fungi (treatment 15). The use of standard NPK fertilization in combination with beneficial fungi promoted the growth of roots in length while reducing their diameter. The measurements also showed that in the control combination where no fertilizers and no beneficial microorganisms were used (treatment 1), the roots had a larger diameter and volume than in the combination with Urea in a 60% dose with strains of filamentous fungi (treatment 11). The full results of root measurements obtained on the scanner are shown in Table 5.

4. Discussion

The tests carried out on strawberry plants showed that Urea combined with beneficial fungi increased the fresh weight of leaves and their surface area to the greatest extent. The applied fertilization methods did not cause any changes in the intensity of the green colour of the leaves. However, the influence of the microbiologically enriched fertilizers and the microorganisms added to the soil on their own on the mineral composition of the leaves was evident. In the group of macroelements, Super Fos Dar 40 enriched with bacteria caused an increase in the level of nitrogen (N) in strawberry leaves, compared to the control combination without fertilization. Mineral fertilization of strawberry plants with NPK only and NPK enriched with bacteria promoted an increase in the level of phosphorus (P) in the leaves. Urea (N) enriched with strains of filamentous fungi produced a similar effect. Under the influence of NPK fertilizer enriched with fungi, the level of calcium (Ca) in the leaves increased markedly.

Table 4. Effect of microbiologically enriched mineral fertilizers on the number and growth characteristics of runners of ‘Marmolada’ strawberry plants (IO Experimental Orchard, Dąbrowice, 2018)
Tab. 4. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na liczbę i cechy wzrostu rozłogów roślin truskawki odmiany ‘Marmolada’ (Sad Doświadczalny IO, Dąbrowice, 2018 r.)

No.	Treatment	Number of runners	Fresh weight of runners [g]	Length of runners [cm]	Number of runner plants	Fresh weight of runner plants [g]
1.	Control – no fertilization (fertilizer combination)	18 ab*	130.3 ab	1846 ab	42 ab	208.0 ab
2.	Control NPK (fertilizer combination)	21 ab	188.3 a-c	2162 ab	50 ab	213.3 ab
3.	Control – no fertilization + strains of filamentous fungi (fertilizer combination)	14 a	147.3 a-c	2039 ab	46 ab	257.0 ab
4.	Control – no fertilization + bacterial strains (fertilizer combination)	25 b	221.3 c	2893 b	59 b	320.0 b
5.	Control NPK + strains of filamentous fungi (fertilizer combination)	22 ab	220.0 c	2998 b	47 ab	258.0 ab
6.	Control NPK + bacterial strains (fertilizer combination)	15 a	121.7 a	1554 a	39 ab	219.0 ab
7.	Polifoska 6 100% + bacterial strains	24 b	194.3 a-c	2588 ab	53 ab	275.3 ab
8.	Urea 100% + strains of filamentous fungi	22 ab	214.7 bc	2185 ab	49 ab	251.0 ab
9.	Polifoska 6 100% + bacterial strains	16 a	174.3 a-c	1523 a	35 a	181.3 a
10.	Super Fos Dar 40 100% + bacterial strains	18 ab	152.7 a-c	1708 a	49 ab	224.3 ab
11.	Urea 60% + strains of filamentous fungi	21 ab	160.0 a-c	2036 ab	39 ab	169.0 a
12.	Polifoska 6 60% + bacterial strains	19 ab	191.7 a-c	2098 ab	48 ab	222.0 ab
13.	Super Fos Dar 40 60% + bacterial strains	24 b	185.3 a-c	2413 ab	46 ab	231.3 ab
14.	Polifoska 6 100%	16 a	125.0 a	1861 ab	41 ab	190.0 a
15.	Urea 100%	26 b	224.7 c	2632 ab	46 ab	248.0 ab
16.	Super Fos Dar 40 100%	20 ab	174.0 a-c	2245 ab	50 ab	241.0 ab

* Means marked with the same letters in a column do not differ significantly at α = 0.05.

Source: own study / Źródło: opracowanie własne

Table 5. Effect of microbiologically enriched mineral fertilizers on the growth characteristics of roots of 'Marmolada' strawberry plants (IO Experimental Orchard, Dąbrowice, 2018)

Tab. 5. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na liczbę i cechy wzrostu rozłogów roślin truskawki odmiany 'Marmolada' (Sad Doświadczalny IO, Dąbrowice, 2018 r.)

No.	Treatment	Root fresh weight [g]	Root dry weight [g]	Root length [cm]	Root surface area [cm^2]	Root diameter [mm]	Root volume [cm^3]	Number of root tips
1.	Control – no fertilization (fertilizer combination)	34.8 ab*	10.2 ab	275.2 a	215.7 a	2.50 d	13.5 c	846 a
2.	Control NPK (fertilizer combination)	43.1 b	12.2 b	415.5 a-c	236.2 a	1.87 a-d	11.3 a-c	1263 ab
3.	Control – no fertilization + strains of filamentous fungi (fertilizer combination)	34.4 ab	10.5 ab	331.6 a-c	211.6 a	2.03 a-d	10.8 a-c	864 a
4.	Control – no fertilization + bacterial strains (fertilizer combination)	39.2 ab	12.1 b	290.8 ab	214.7 a	2.38 b-d	12.8 c	908 ab
5.	Control NPK + strains of filamentous fungi (fertilizer combination)	33.2 ab	9.5 ab	606.5 c	236.4 a	1.29 a	7.4 ab	1684 ab
6.	Control NPK + bacterial strains (fertilizer combination)	35.8 ab	9.9 ab	365.6 a-c	231.2 a	2.03 a-d	11.7 bc	1114 ab
7.	Polifoska 6 100% + bacterial strains	25.7 ab	7.5 ab	349.0 a-c	186.7 a	1.78 a-d	8.3 a-c	932 ab
8.	Urea 100% + strains of filamentous fungi	32.2 ab	9.2 ab	351.7 a-c	208.4 a	1.99 a-d	10.4 a-c	1141 ab
9.	Polifoska 6 100% + bacterial strains	40.6 b	12.0 b	362.8 a-c	202.2 a	1.77 a-d	9.0 a-c	1080 ab
10.	Super Fos Dar 40 100% + bacterial strains	32.4 ab	11.1 ab	559.5 a-c	240.7 a	1.42 ab	8.4 a-c	1617 ab
11.	Urea 60% + strains of filamentous fungi	21.1 a	5.9 a	580.0 bc	204.4 a	1.26 a	6.3 a	1506 ab
12.	Polifoska 6 60% + bacterial strains	39.5 ab	8.7 ab	286.0 ab	216.1 a	2.42 cd	13.0 c	856 a
13.	Super Fos Dar 40 60% + bacterial strains	25.6 a	7.3 ab	456.6 a-c	203.8 a	1.43 a-c	7.4 ab	1351 ab
14.	Polifoska 6 100%	28.0 ab	7.8 ab	401.2 a-c	203.1 a	1.65 a-d	8.4 ac	1123 ab
15.	Urea 100%	23.4 a	6.8 a	568.5 a-c	212.7 a	1.32 a	6.5 ab	1818 b
16.	Super Fos Dar 40 100%	41.4 b	12.3 b	491.0 a-c	260.9 a	1.76 a-d	11.5 a-c	1122 ab

* Means marked with the same letters in a column do not differ significantly at $\alpha = 0.05$.

Source: own study / Źródło: opracowanie własne

The nitrogen content of the leaves of the tested strawberry plants was within the limits of low and deficit content, based on the limiting values of mineral content [39]. The use of Super Fos Dar 40 enriched with bacteria had a positive influence on the nitrogen content of the leaves. Fertilization with NPK only, NPK enriched with bacteria, and Urea with strains of filamentous fungi promoted the accumulation of phosphorus in the leaves. The phosphorus content of the leaves of the tested strawberry plants was within the limits of high content, according to the limiting values of mineral content [39]. The use of mineral fertilizers, e.g. Super Fos Dar 40, reduced the level of phosphorus in the leaves, which has a positive effect on the optimal supply of plants with this element. NPK fertilization combined with beneficial fungi contributed to an increase in calcium levels in strawberry leaves. The concentrations of macroelements such as potassium and magnesium in the leaves of strawberry plants were high and optimal, respectively, considering the limiting values [39], with the exception of the control combination without fertilization in the case of potassium. The experimental treatments did not significantly modify the amounts of B and Cu in the leaves, but had an effect on the levels of Fe, Mn and Zn. Higher concentrations of microelements were found in the combinations with the mineral fertilizers enriched with beneficial bacteria.

The fertilizers enriched with microorganisms, according to the study, can improve the growth of aboveground parts of strawberry plants already in the first year of vegetation. As a result of using bacteria of the genus *Bacillus*, the length of runners, the number of runner plants and their weight increased. There is evidence in the scientific literature that colonization of the root system by AMF and filamentous fungi can change its morphological structure, e.g. the size of roots, their topographical layout, as well as their surface area and volume [10, 11, 14, 21]. In the study, the strawberry plants fertilized conventionally with NPK, those treated with a full dose of Polifoska 6 enriched with bacterial strains, and those fertilized with a full dose of Super Fos Dar 40 produced roots of a greater mass than the plants treated with Urea in a 60% dose with strains of filamentous fungi and those fertilized only with a full dose of Urea without filamentous fungi. The use of standard NPK fertilization in combination with beneficial fungi promoted the growth of roots in length while reducing their diameter, and Urea alone in a 100% dose caused an increase in the number of root tips. The obtained results in this respect coincide with the data in previously published works [10, 11, 31]. The impact of the applied products on the growth characteristics of the aboveground part and roots of strawberry plants is expected to be more evident in the subsequent years of the study. In the first year of conducting the experiment, special attention was paid to the vegetative growth of plants. More results showing the advantages and possible disadvantages of the use of microorganisms and some fertilizers enriched with them will be available only in the next two years, when the plants bear fruit. In 2018, as a result of the removal of inflorescences, the plants did not bear fruit. An assessment of yielding in the first year would not meaningful because the fruit would only be produced from the buds that had already formed on the plantlets before they were planted [13].

5. Conclusions

1. The presence of filamentous fungi and bacterial strains of the genus *Bacillus* in fertilizers has a modifying effect on the mineral composition of strawberry leaves. The NPK fertilizer without the microorganisms caused an increase in the phosphorus content of the leaves of strawberry plants, and, when enriched with the strains of filamentous fungi, also in the level of calcium. Super Fos Dar 40 at a concentration of 100% in combination with the bacterial strains caused an increase in the level of nitrogen in the leaves of strawberry plants.
2. After fertilizing strawberry plants with the fertilizer Polifoska 6 at a concentration of 60% containing the strains of bacteria, there occurred in the leaves a significant increase in the level of iron, and after using this fertilizer at a concentration of 100% together with the bacteria – an increase in magnesium content.
3. The bacteria and filamentous fungi used alone (without mineral fertilization) intensified the growth of strawberry plants, causing a greater increase in the length of runners, and also an increase in the number of runner plants and their fresh and dry weight.
4. Urea at a concentration of 100% enriched with the strains of filamentous fungi caused a greater increase in the fresh weight of runners and in root growth in length. Super Fos Dar 40 at a concentration of 100% without the microorganisms increased the number of root tips.

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