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EFFECT OF MICROBIOLOGICALLY ENRICHED FERTILIZERS ON THE VEGETATIVE GROWTH OF STRAWBERRY PLANTS IN CONTAINER-BASED CULTIVATION AT DIFFERENT LEVELS OF IRRIGATION

Summary

The experiment was established in the SGGW Experimental Field in Skierniewice in the spring of 2018 in four replications. It was conducted on strawberry plants of the cultivar 'Marmolada' and included the following experimental combinations (in two variants 100% hydration and 50% hydration): 1. Control – no fertilization; 2. Control – standard NPK fertilization; 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. In 2018, there was no fruiting because all the inflorescences of the strawberry plants had been removed. The leaves were analyzed for mineral content (macro- and microelements). In the autumn, the runners were cut off and their number, fresh weight and length and also the number and fresh weight of the runner plants were determined. The results of the first year of the study showed that filamentous fungi and beneficial bacteria used together with the fertilizers tested in the experiment with strawberry plants (Urea, Polifoska 6, Super Fos Dar 40) favourably improved the growth of runners and runner plants, and increased the concentration of some minerals and macro- and microelements in the leaves. The amount of water supplied to the strawberry plants fertilized with the different mineral fertilizers enriched with beneficial bacteria and filamentous fungi affected the growth of the vegetative parts of plants. The fertilizer Super Fos Dar 40 in a 100% dose enriched with bacterial strains of the genus Bacillus, with a substantial deficit of water in the soil, stimulated the growth of runners and runner plants, and effectively limited the effects of drought.

***Keywords**: Fragaria × ananassa, fertilization, beneficial microorganisms, drought stress*

WPŁYW NAWOZÓW WZBOGACONYCH MIKROBIOLOGICZNIE NA WZROST WEGETATYWNY TRUSKAWKI W UPRAWIE KONTENEROWEJ PRZY ZRÓŻNICOWANYM POZIOMIE NAWADNIANIA

Streszczenie

Doświadczenie założono wiosną w 2018 roku w czterech powtórzeniach, na Polu Doświadczalnym SGGW w Skierniewicach. Doświadczenie prowadzono w dwóch wariantach 100% nawodnienie i 50% nawodnienie w następujących kombinacjach: 1. Kontrola – bez nawożenia; 2.Standardowe nawożenie 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. Standardowe nawożenie NPK + grzyby; 6. Standardowe nawożenie 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. W 2018 roku owocowania nie było ponieważ wszystkie kwiatostany roślin zostały usunięte. W liściach określano zawartość składników mineralnych (makro- i mikroelementów). Jesienią odcinano rozłogi i określano ich liczbę, świeżą masę, długość, liczbę oraz świeżą masę sadzonek rozłogowych. Wyniki pierwszego roku badań wykazały, że, grzyby strzępkowe i bakterie pożyteczne stosowane razem z nawozami badanymi w doświadczeniu z roślinami truskawki (mocznik, Polifoska 6, Super Fos Dar 40) wpływają korzystnie na poprawę wzrostu rozłogów i sadzonek rozłogowych oraz wzrost zawartości niektórych składników mineralnych oraz makro- i mikroelementów w liściach. Ilość dostarczanej wody roślinom truskawki, nawożonym różnymi nawozami mineralnymi wzbogaconymi bakteriami pożytecznymi i grzybami strzępkowymi, ma wpływ na wzrost wegetatywnych części roślin. Nawóz Super Fos Dar 40 w dawce 100% wzbogacony szczepami bakterii rodzaju Bacillus, przy wyraźnym deficycie wody w glebie, stymulował wzrost rozłogów i sadzonek rozłogowych roślin truskawki i skutecznie ograniczał skutki suszy.

***Słowa kluczowe**: Fragaria × ananassa, nawożenie, pożyteczne mikroorganizmy, stres suszy*

1. Introduction

Intensive mineral fertilization increases production costs on the one hand, while on the other it causes pollution of the soil environment, drinking water and air [5, 33]. One of the solutions proposed to protect the environment and human health is the implementation into agricultural practice of natural technologies of cultivating crop plants and their fertilization through the use of bio-fertilizers. [11, 16, 26, 32]. It has been shown in many research studies that the use of fertilizers enriched with beneficial strains of bacteria and fungi increases their effectiveness in plant cultivation [8, 9, 11, 15]. Due to the presence of beneficial microorganisms in the soil environment, physiological processes in plants are strengthened, plant growth and yielding increase, and plant resistance to environmental and biotic stresses is improved [10, 36].

In modern agriculture, and especially in organic crop production, fertilizers that have a positive impact on the environment have long been sought [1, 25]. The availability of traditional fertilizers of organic origin such as manure and compost is increasingly limited. One of the innovative solutions tested in recent years is the enrichment of organic fertilizers, composts and liquid plant growth promoters with consortia of beneficial microorganisms [20, 28, 30]. The presence of native mycorrhizal and filamentous fungi and beneficial bacterial strains in new bioproducts introduced into the market ensures their better adaptation and survival under favourable environmental conditions [30]. Arbuscular and filamentous fungi 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 reduction in the use of chemicals in crop production [17, 18, 19, 24, 31].

Many scientific reports suggest that soil microorganisms and plant extracts can positively influence growth and yield characteristics of plants of high economic importance, including strawberry [1, 2, 14, 16, 17, 18, 19, 31]. They have shown that microorganisms act beneficially by decomposing and mobilizing organic matter, and incorporating its elements into biological processes [3, 20, 28, 35, 37, 38]. A particularly important role in this process is attributed to mycorrhizal fungi [11, 25, 31]. They produce in the soil environment numerous spores from which mycelium hyphae grow in different periods of vegetation on the roots of strawberry plants and other crops, thus promoting their growth. In the literature, opinions can be found that the use of fertilizers enriched with beneficial bacterial and fungal strains increases their effectiveness in plant nutrition [8, 9, 11, 15]. Thanks to the action of microorganisms, the physiological processes taking place in the plant are strengthened, subsequently leading to the intensification of plant growth and yielding. Plant resistance to environmental and biotic stresses also increases [10, 34, 36, 39].

Water, as pointed out by many authors, is one of the most important factors affecting the life of crop plants and microorganisms coexisting with them [34, 39]. The fact that soil microorganisms, including fungi and bacteria, can limit the stress of drought caused by a deficit of water supplied to plants during vegetation has been reported by many authors of research papers on this problem [6, 14, 34, 39]. The mechanism of cooperation between crop plants and microorganisms has not been thoroughly examined yet. There are reports indicating that they behave differently in an optimally irrigated environment and where there is a persistent or periodic water deficit in the soil [10, 39]. The activity of microorganisms in the rhizosphere, as pointed out by some authors, is a factor that positively influences not only the growth of plants but also their degree of resistance to certain diseases [21, 27, 30]. Thanks to rhizosphere bacteria and mycorrhizal and filamentous fungi present on the surface of roots or near them, plants can better absorb from the soil macro- and microelements needed by them for proper functioning in an environment partially degraded by human activity, and also where this phenomenon detrimental to the plants does not yet exist [7, 26, 32].

The aim of the study is to evaluate the growth and development of strawberry plants grown in stoneware containers filled with a podzolic soil from an organic orchard under conditions of optimal soil hydration and also subjected to drought stress. The soil which was the substrate for strawberry plants was treated with fertilizers enriched with microorganisms, i.e. bacteria of the genus *Bacillus,* and with a consortium of filamentous fungi. In the first year of the study, the main attention was focused on the growth of plants, while in the following years, their fruiting will also be evaluated.

Research hypothesis

Innovative microbiologically enriched fertilizers favourably affect the growth and development of strawberry plants subjected to drought stress in comparison with the control treatment without fertilization and NPK fertilization.

2. Materials and methods

The experiment will be carried out for three consecutive years (2018-2020) in the SGGW Experimental Field in Skierniewice (Central Poland, latitude 51.9625 N, longitude 20.1624 E, 128 metres above sea level) on strawberry plants of the cultivar 'Marmolada' (synonym 'Onebor'). Frigo A+ plantlets with a crown diameter of 15-18 mm were planted in early May in stoneware containers with a diameter of 0.40 m and a height of 1.20 m, containing about 120 litres of podzolic soil with a pH of 6.2 (in KCl). The containers with the plants are buried in the ground in an open field. Each of them has three plants growing at a distance of 25 cm from one another. Prior to the experiment, the concentration of macroelements in the soil was as follows: P – 7.5; K – 12.4; Mg – 5.8 mg/100 g, and of microelements: B – 2.4; Cu – 4.8; Fe – 862; Mn – 75.5; Na – 4.35; Zn – 3.7 mg/1000 g. The organic matter content of the soil was 1.2%. 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/).

The experiment, set up in three replications, consisted of two blocks of plants fertilized equally with mineral fertilizers enriched with beneficial bacteria and filamentous fungi, but under conditions of varied irrigation levels. In one block, plants were optimally drip-irrigated according to the indications of tensiometers, while in the other with only half the amount of water fed in the first block.

The experiment included the following experimental combinations:

1. Control (no treatment) – unfertilized podzolic soil (composition given above).
2. Standard NPK (Control) soil fertilization. 12 g of Super Fos Dar 40 granulated fertilizer, 50 g of potassium salt and 35 g of Urea were used for each container before planting. Urea in the amount of 12 g per container was also used in mid-summer.
3. Control (no fertilization) – beneficial soil fungi were added in the amount of 5.25 g per container immediately after planting, thoroughly mixing them with the soil. The mixture of beneficial soil fungi contained two species: *Aspergillus niger* and *Purpureocillium lilacinum*.
4. Control (no fertilization) – beneficial bacteria were added in the amount of 3.83 g per container immediately after

planting, thoroughly mixing them with the soil. The mixture of beneficial bacteria contained three strains of *Bacillus* (*Bacillus* sp., *Bacillus amyloliquefaciens* and *Paenibacillus polymyxa*).

5. Standard NPK – soil fertilized as in point 2, with beneficial soil fungi listed in point 3.
6. Standard NPK – soil fertilized as in point 2, with beneficial bacteria applied to the soil in the containers as in point 4.
7. Polifoska 6 in a 100% dose with three strains of bacteria of the genus *Bacillus*, which had been incorporated into the fertilizer during the production of granules. It was applied before planting at 26 g per container. Urea in the amount of 30 g was applied before planting and in a dose of 20 g in mid-summer. Potassium salt in the amount of 33 g was applied before planting.
8. Urea in a 100% dose enriched with strains of filamentous fungi with the species and quantitative composition as in point 3. In addition, 50 g of potassium salt, 35 g of Urea and 12 g of Super Fos Dar 40 fertilizer were added to each container before planting. Urea in the amount of 20 g was also applied in mid-summer.
9. Polifoska 6 in a 100% dose with three strains of *Bacillus* bacteria in the amount and with the species composition as in point 4. Before planting, 26 g of it, 33 g of potassium salt and 30 g of Urea were applied to each container. Urea in the amount of 20 g was also used in the second dose applied in mid-summer.
10. Super Fos Dar 40 in a 100% dose enriched with three strains of *Bacillus* bacteria in the amount of 3.83 g per container. Before planting the plants, the soil was fertilized with 50 g of potassium salt, Super Fos Dar 40 fertilizer in the amount of 12 g and Urea – the first time in the amount of 35 g before planting, and the second time in a dose of 20 g in the middle of summer.
11. Urea in a 60% dose enriched with strains of filamentous fungi with the species and quantitative composition as in point 3. In addition, 30 g of potassium salt and 20 g of Urea, and 7 g of Super Fos Dar 40 fertilizer were applied to each container before planting. Urea in the amount 12 g was also applied in mid-summer.
12. Polifoska 6 in a 60% dose enriched with three strains of *Bacillus* bacteria as in point 9. Before planting the plants, 14 g of Polifoska 6, 30 g of potassium salt, and 18 g of Urea were applied to each container. Urea in the amount of 12 g was also applied in mid-summer.
13. Super Fos Dar 40 in a 60% dose enriched with three strains of *Bacillus* bacteria as in point 12. Before planting, 7 g of Super Fos Dar 40 fertilizer, 30 g of potassium salt, and 20 g of Urea were added to the soil in each container. Urea in the amount of 12 g per container was also used to fertilize the strawberry plants in the middle of summer.

In the first year after planting the strawberry plants, the inflorescences were systematically removed so that the development of fruit would not inhibit plant growth [13]. The effectiveness of the microbiologically enriched fertilizers and the microorganisms added to the soil on their own, as well as the varied irrigation of the plantation was evaluated on the basis of the mineral content of the leaves and the intensity of the growth of runners.

The concentration of minerals in the leaves was determined on the basis of a sample of 25 leaves taken from plants from each plot in mid-August. The measurements of runners, which were cut off in the second half of September, included: the number of runners taken from three plants from each plot, fresh weight of runners (g), length of runners (cm), number of runner plants, fresh weight of runner plants (g).

2.1. Analysis of macro- and microelements in leaves

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 in 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.

2.2. 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 are marked with the same letters.

2.3. Characteristics of Super Fos Dar 40 fertilizer, 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 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 containing 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 is a granulated fertilizer from the group of nitrogen fertilizers, containing 46% (N) in amide form.

3. Results

In the part of the experiment in which the strawberry plants were irrigated optimally, as indicated by tensiometers, the NPK fertilizer enriched with bacteria significantly increased the nitrogen (N) level in the leaves. A low level of this component in the leaves was found in the combinations in which Urea with filamentous fungi and Super Fos Dar 40 at a reduced dose with bacterial strains were used. The plants without fertilization and growing where the filamentous fungi had been introduced into the soil as well as under standard NPK fertilization had the highest level of phosphorus (P) in the leaves. Low levels of phosphorus in the leaves were shown by the plants fertilized with a full dose of Super Fos Dar 40 with bacterial strains and in the combination with a reduced dose of Urea combined with strains of filamentous fungi. The accumulation of magnesium (Mg) in the leaves was promoted by beneficial fungi used without mineral fertilization. The least amounts of magnesium were contained in the leaves of the plants treated with Urea at full dose enriched with strains of filamentous fungi, Super Fos Dar 40 at full dose with useful bacteria, and Polifoska 6 and Super Fos Dar 40 in reduced doses together with beneficial bacteria. The applied fertilization treatments did not have a significant impact on the level of potassium (K) or calcium (Ca) in strawberry leaves. (Table 1).

The different methods of fertilizing strawberry plants under conditions of optimal irrigation did not cause significant changes in the level of boron (B) in the leaves, whereas there were differences in the amounts of copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) (Table 2). The largest amount of copper was in the leaves of the plants from the control combination growing in the soil without additional fertilization and treatment with microorganisms.

Table 1. Effect of microbiologically enriched mineral fertilizers on the concentration of macroelements in the leaves of ‘Marmolada’ strawberry plants growing under optimal irrigation conditions – 100% of water dose (Container-based experiment, Experimental Field, SGGW, Skierniewice, 2018)

Tab. 1. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na zawartość makroelementów w liściach roślin truskawki odmiany ‘Marmolada’ rosnących w optymalnych warunkach nawadniania - 100% dawki wody (Doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 2018 r.)

No.	Treatment	N	P	K	Mg	Ca
		%				
1.	Control (no fertilization) (fertilizer combination)	1.55 a-c*	0.32 e	2.15 a	0.24 cd	1.54 a
2.	Control NPK (fertilizer combination)	1.68 b-d	0.28 c	2.13 a	0.22 a-c	1.75 a
3.	Control + fungal strains (fertilizer combination)	1.71 b-d	0.33 e	2.13 a	0.25 d	1.58 a
4.	Control + bacterial strains (fertilizer combination)	1.72 cd	0.31 de	2.26 a	0.22 a-c	1.71 a
5.	NPK + fungal strains (fertilizer combination)	1.65 a-d	0.31 de	2.26 a	0.22 a-c	1.79 a
6.	NPK + bacterial strains (fertilizer combination)	1.96 e	0.32 e	2.08 a	0.24 cd	1.54 a
7.	Polifoska 6 100% + bacterial strains	1.85 de	0.29 cd	2.19 a	0.23 b-d	1.78 a
8.	Urea 100% + fungal strains	1.43 a	0.29 cd	2.22 a	0.20 a	1.78 a
9.	Polifoska 6 100% + bacterial strains	1.53 a-c	0.31 de	2.11 a	0.21 ab	1.80 a
10.	Super Fos Dar 40 100% + bacterial strains	1.72 cd	0.21 a	1.73 a	0.20 a	1.61 a
11.	Urea 60% + fungal strains	1.54 a-c	0.21 a	1.71 a	0.21 ab	1.69 a
12.	Polifoska 6 60% + bacterial strains	1.48 ab	0.24 b	2.88 a	0.20 a	1.66 a
13.	Super Fos Dar 40 60% + bacterial strains	1.42 a	0.22 ab	1.84 a	0.20 a	1.73 a

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

Source: own study / Źródło: opracowanie własne

Table 2. Effect of microbiologically enriched mineral fertilizers on the concentration of microelements in the leaves of ‘Marmolada’ strawberry plants growing under optimal irrigation conditions – 100% of water dose (Container-based experiment, Experimental Field, SGGW, Skierniewice, 2018)

Tab. 2. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na zawartość mikroelementów w liściach roślin truskawki odmiany ‘Marmolada’ rosnących w optymalnych warunkach nawadniania - 100% dawki wody (Doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 2018 r.)

No.	Treatment	B	Cu	Fe	Mn	Zn
		mg/kg				
1.	Control (no fertilization) (fertilizer combination)	32.5 a*	6.04 c	182 g	127 f	168 d
2.	Control NPK (fertilizer combination)	32.2 a	4.43 a-c	162 d	112 e	175 f
3.	Control + fungal strains (fertilizer combination)	32.2 a	5.77 c	148 c	78.8 a	148 b
4.	Control + bacterial strains (fertilizer combination)	30.8 a	4.90 a-c	141 b	84.7 b	199 j
5.	NPK + fungal strains (fertilizer combination)	32.1 a	4.87 a-c	176 f	100 d	189 h
6.	NPK + bacterial strains (fertilizer combination)	31.1 a	5.55 bc	175 f	95.3 c	162 c
7.	Polifoska 6 100% + bacterial strains	31.4 a	4.65 a-c	200 h	96.1 c	199 j
8.	Urea 100% + fungal strains	36.6 a	4.44 a-c	209 i	86.6 b	195 i
9.	Polifoska 6 100% + bacterial strains	31.7 a	4.28 a-c	198 h	133 g	194 i
10.	Super Fos Dar 40 100% + bacterial strains	31.5 a	3.52 a	116 a	126 f	140 a
11.	Urea 60% + fungal strains	29.3 a	3.24 a	171 e	152 h	172 e
12.	Polifoska 6 60% + bacterial strains	33.6 a	3.63 ab	142 b	173 i	184 g
13.	Super Fos Dar 40 60% + bacterial strains	32.7 a	3.62 ab	149 c	151 h	233 k

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

Source: own study / Źródło: opracowanie własne

The lowest level of copper in the leaves was found where Super Fos Dar 40 at full dose combined with beneficial bacteria and Urea in a 60% dose with strains of filamentous fungi were used. The highest iron content was found in the leaves of the plants fertilized with a full dose of Urea enriched with strains of filamentous fungi, and the lowest – where Super Fos Dar 40 in combination with useful bacteria was used. The manganese content of the leaves ranged from 78.8 mg/kg to 152 mg/kg. The lowest level was in the treatment in which only beneficial fungi were added to the soil, and the highest – after using Polifoska 6 in a 60% dose and Super Fos Dar 40 also in a reduced amount combined with bacterial strains. The lowest level of zinc was found in the leaves of plants fertilized with a full dose of Super Fos Dar 40 with bacterial strains, and the highest when the reduced amount of Super Fos Dar 40 was added to the soil also with bacterial strains.

The standard NPK mineral fertilization promoted the formation of runners by strawberry plants and their growth in length. Good results in this respect were also obtained after the application of NPK fertilization together with beneficial bacteria. The lowest number of runners and those of the smallest length and fresh weight were found after fertilization of strawberry plants with Urea in a 60% dose together with strains of filamentous fungi, as well as Super Fos Dar 100% and 60% with beneficial bacteria, and Polifoska 6 in a 60% dose. The largest number and mass of runner plants were produced by the plants fertilized with standard NPK doses after enriching the soil with beneficial bacteria (Table 3).

Under drought stress, NPK fertilization combined with the addition to the soil of strains of filamentous fungi caused a significant increase in the nitrogen (N) content of the leaves of strawberry plants. The lowest level of this component was in the leaves of the plants growing in the soil without any additional fertilization. The largest amounts of phosphorus were contained in the leaves of the plants treated with Super Fos Dar 40 in a 100% dose enriched with bacteria, and those treated with Urea in a 60% dose enriched with strains of filamentous fungi. The lowest amounts of phosphorus were found in the leaves of the plants fertilized with NPK together with the addition of beneficial bacteria to the soil. The level of calcium in the leaves increased after NPK fertilization and the application of Polifoska 6 with the addition of beneficial bacteria to the soil, and following the treatment with a 60% dose of Urea enriched with strains of filamentous fungi. The least amount of this component was in the leaves of the plants without mineral fertilization, with only beneficial bacteria applied to the soil. There were no significant differences in the potassium content of the leaves of the plants growing under drought stress and fertilized with the different methods (Table 4).

The applied fertilization treatments had no significant effect on the copper content of the leaves of the plants grown under drought stress conditions. Some differences in the level of other microelements were evident. The strawberry plants that had not been fertilized at all had the highest amounts of boron, manganese and zinc in the leaves. The accumulation of iron in the leaves was promoted by the addition of beneficial fungi to the soil. In turn, the least amount of iron was in the leaves of the plants fertilized conventionally with NPK, whereas the lowest level of manganese was found after the application of Polifoska 6 at a reduced dose together with the addition of beneficial bacteria to the soil. The smallest amount of zinc was contained in the leaves of the plants with standard NPK fertilization with the addition of beneficial fungi to the soil (Table 5).

Table 3. Effect of microbiologically enriched mineral fertilizers on the growth of aboveground parts of ‘Marmolada’ strawberry plants irrigated optimally – 100% of water dose. (Container-based experiment, Experimental Field, SGGW, Skierniewice, 2018)

Tab. 3. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na wzrost nadziemnych części roślin truskawki odmiany ‘Marmolada’ nawadnianych optymalnie - 100% dawki wody. (Doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 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)	27.7 a-e*	107.0 b-d	1742 ab	41.0 a-c	76.3 ab
2.	Control NPK (fertilizer combination)	31.3 e	126.0 d	2745 b	53.7 cd	216.0 cd
3.	Control + fungal strains (fertilizer combination)	30.3 de	119.0 cd	2089 ab	55.0 cd	172.7 cd
4.	Control + bacterial strains (fertilizer combination)	29.7 c-e	125.3 cd	2331 ab	54.0 cd	196.7 cd
5.	NPK + fungal strains (fertilizer combination)	29.0 b-e	121.0 cd	2220 ab	48.3 b-d	215.0 cd
6.	NPK + bacterial strains (fertilizer combination)	32.3 e	139.3 d	2405 ab	59.3 d	232.0 d
7.	Polifoska 6 100% + bacterial strains	20.7 a-c	131.3 d	1570 ab	41.0 a-c	196.3 cd
8.	Urea 100% + fungal strains	20.3 ab	138.3 d	2088 ab	27.3 a	146.7 bc
9.	Polifoska 6 100% + bacterial strains	23.3 a-e	155.7 d	1814 ab	39.0 a-c	219.3 cd
10.	Super Fos Dar 40 100% + bacterial strains	27.0 a-e	62.7 ab	1509 ab	39.3 a-c	78.3 ab
11.	Urea 60% + fungal strains	19.7 a	55.3 a	1172 a	32.3 ab	58.7 a
12.	Polifoska 6 60% + bacterial strains	22.0 a-d	60.0 ab	1234 ab	37.3 a-c	66.7 ab
13.	Super Fos Dar 40 60% + bacterial strains	20.3 ab	73.9 a-c	1942 ab	37.7 a-c	70.7 ab

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

Source: own study / Źródło: opracowanie własne

Table 4. Effect of microbiologically enriched mineral fertilizers on the concentration of macroelements in the leaves of 'Marmolada' strawberry plants growing under drought stress – 50% of water dose (Container-based experiment, Experimental Field, SGGW, Skierniewice, 2018).

Tab. 4. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na zawartość makroelementów w liściach roślin truskawki odmiany 'Marmolada' rosnących w warunkach stresu suszy - 50% dawki wody (Doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 2018 r.).

No.	Treatment	N	P	K	Mg	Ca
		%				
1.	Control (no fertilization) (fertilizer combination)	1.42 a*	0.27 ef	1.77 a	0.20 ab	1.67 g
2.	Control NPK (fertilizer combination)	1.64 d	0.28 fg	1.82 a	0.19 a	1.63 ef
3.	Control + fungal strains (fertilizer combination)	1.42 a	0.22 bc	1.75 a	0.20 ab	1.59 d
4.	Control + bacterial strains (fertilizer combination)	1.62 d	0.23 b-d	1.73 a	0.21 ab	1.47 a
5.	NPK + fungal strains (fertilizer combination)	2.04 j	0.25 c-e	1.83 a	0.20 ab	1.56 c
6.	NPK + bacterial strains (fertilizer combination)	1.51 b	0.18 a	1.70 a	0.20 ab	1.81 i
7.	Polifoska 6 100% + bacterial strains	1.73 f	0.21 ab	2.00 a	0.21 ab	1.81 i
8.	Urea 100% + fungal strains	1.99 i	0.26 d-f	1.89 a	0.20 ab	1.65 fg
9.	Polifoska 6 100% + bacterial strains	1.85 h	0.22 bc	1.93 a	0.22 b	1.75 h
10.	Super Fos Dar 40 100% + bacterial strains	1.63 d	0.31 g	2.15 a	0.20 ab	1.77 h
11.	Urea 60% + fungal strains	1.59 c	0.31 g	2.24 a	0.20 ab	1.82 i
12.	Polifoska 6 60% + bacterial strains	1.68 e	0.29 fg	2.11 a	0.21 ab	1.52 b
13.	Super Fos Dar 40 60% + bacterial strains	1.77 g	0.27 ef	1.90 a	0.21 ab	1.61 de

* 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 concentration of microelements in the leaves of 'Marmolada' strawberry plants growing under drought stress – 50% of water dose (Container-based experiment, Experimental Field, SGGW, Skierniewice, 2018)

Tab. 5. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na zawartość mikroelementów w liściach roślin truskawki odmiany 'Marmolada' rosnących w warunkach stresu suszy - 50% dawki wody (Doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 2018 r.)

No.	Treatment	B	Cu	Fe	Mn	Zn
		mg/kg				
1.	Control (no fertilization) (fertilizer combination)	36.3 c*	4.42 a	164 g	265 j	223 j
2.	Control NPK (fertilizer combination)	36.1 c	4.00 a	115 a	202 i	155 c
3.	Control + fungal strains (fertilizer combination)	33.7 a-c	4.01 a	285 i	122 d	214 i
4.	Control + bacterial strains (fertilizer combination)	29.9 a	4.34 a	135 c	160 g	173 e
5.	NPK + fungal strains (fertilizer combination)	30.6 ab	4.39 a	140 d	122 d	115 a
6.	NPK + bacterial strains (fertilizer combination)	29.5 a	3.37 a	274 h	146 f	212 i
7.	Polifoska 6 100% + bacterial strains	29.1 a	3.79 a	161 f	120 d	192 h
8.	Urea 100% + fungal strains	34.6 a-c	4.22 a	163 fg	135 e	169 d
9.	Polifoska 6 100% + bacterial strains	33.3 a-c	3.81 a	135 c	186 h	184 g
10.	Super Fos Dar 40 100% + bacterial strains	29.8 a	4.92 a	150 e	109 c	181 f
11.	Urea 60% + fungal strains	29.2 a	4.88 a	142 d	86.5 b	181 f
12.	Polifoska 6 60% + bacterial strains	30.0 a	5.26 a	132 b	69.4 a	135 b
13.	Super Fos Dar 40 60% + bacterial strains	31.0 a-c	4.91 a	151 e	87.4 b	167 d

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

Source: own study / Źródło: opracowanie własne

With the limited access of plants to water, only Super Fos Dar 40 in a 100% dose enriched with bacterial strains significantly increased or tended to increase all of the measured strawberry plant growth characteristics regarding the number, fresh weight and length of runners and runner plants. The other methods of fertilizing strawberry plants had no significant effect on the size of the parameters of the plant parts tested (Table 6).

4. Discussion

A comparison of the results of chemical analyses of the leaves of the strawberry plants growing in optimally irrigated stoneware containers and those growing in simulated drought conditions shows that in terms of mineral content the obtained data are clearly different from each other. With optimal irrigation of plants, the NPK fertilizer enriched with filamentous fungi increased nitrogen and phosphorus levels, while Urea with fungal strains – the levels of boron and iron. By comparison, under drought stress, under the influence of NPK enriched with fungi, the level of nitrogen increased significantly as in the case of optimal irrigation, while under the influence of NPK fertilizers and Polifoska 6 at a concentration of 100% together with bacterial strains there was a significant increase in the level of calcium. The increase in calcium content was also caused by Urea in a 60% dose enriched with fungi, and Super Fos Dar 40 in a full dose in combination with bacteria. The former also increased the level of phosphorus in the leaves. The above comparison shows that external factors and those occurring in the rhizosphere zone have a significant influence on the mineral composition of the leaves, and consequently on the physiological condition of plants [11, 31].

Table 6. Effect of microbiologically enriched mineral fertilizers on some growth parameters of aboveground parts of 'Marmolada' strawberry plants growing under drought stress – 50% of water dose (Container-based experiment, Experimental Field, SGGW, Skierniewice, 2018)

Tab. 6. Wpływ nawozów mineralnych wzbogaconych mikrobiologicznie na niektóre cechy wzrostu nadziemnych części roślin truskawki odmiany 'Marmolada' rosnących w warunkach stresu suszy - 50% dawki wody (Doświadczenie wazonowe, Pole Doświadczalne, SGGW, Skierniewice, 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)	25.3 ab*	83.0 ab	1352.3 ab	31.0 ab	69.0 ab
2.	Control NPK (fertilizer combination)	22.3 ab	67.0 ab	1332.0 ab	35.7 ab	83.3 a-c
3.	Control + fungal strains (fertilizer combination)	21.3 ab	63.0 ab	1757.0 ab	31.3 ab	78.7 a-c
4.	Control + bacterial strains (fertilizer combination)	17.0 ab	44.7 a	771.7 a	24.0 a	46.3 a
5.	NPK + fungal strains (fertilizer combination)	18.3 ab	50.7 ab	1017.7 a	36.0 ab	79.7 a-c
6.	NPK + bacterial strains (fertilizer combination)	16.7 a	60.7 ab	1062.0 a	20.7 a	71.3 a-c
7.	Polifoska 6 100% + bacterial strains	18.7 ab	71.0 ab	1225.0 ab	30.7 ab	123.0 a-c
8.	Urea 100% + fungal strains	19.0 ab	68.7 ab	1267.7 ab	29.3 ab	67.7 ab
9.	Polifoska 6 100% + bacterial strains	21.3 ab	104 a-c	1526.0 ab	36.7 ab	160.0 b-d
10.	Super Fos Dar 40 100% + bacterial strains	31.3 b	165.0 c	2561.0 b	55.7 b	229.0 d
11.	Urea 60% + fungal strains	26.7 ab	121.0 bc	2129.3 ab	41.0 ab	157.7 b-d
12.	Polifoska 6 60% + bacterial strains	20.7 ab	114.3 a-c	1677.7 ab	39.3 ab	172.0 cd
13.	Super Fos Dar 40 60% + bacterial strains	20.0 ab	92.3 ab	2129.7 ab	31.7 ab	139.0 a-d

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

Source: own study / Źródło: opracowanie własne

With the optimal supply of strawberry plants in water in the experiment, the level of some macro- and microelements increased under the influence of the fertilizers enriched with soil microorganisms, and the weight and number of runners and runner plants also increased. Standard NPK fertilization with the addition of *Bacillus* strains to the soil was particularly effective in this respect.

In the experiment, the strawberry plants under the simulated drought stress fertilized conventionally with NPK and the addition of strains of filamentous fungi to the soil accumulated exceptionally high amounts of nitrogen, and in the presence of bacterial strains the same fertilizer and also Polifoska 6 caused a marked increase in the calcium content of the leaves. However, Urea in a 60% dose enriched with fungi and Super Fos Dar 40 in a 100% dose with bacterial strains caused an increase in the levels of phosphorus and potassium in the leaves of those plants.

Size measurements of the aboveground parts produced by strawberry plants, i.e. the number, fresh weight and length of runners as well as the number and fresh weight of runner plants show that only Super Fos Dar 40 at a concentration of 100% enriched with bacterial strains favourably increases in the drought zone the size of all the elements of the tested plant parts. This fertilizer, according to preliminary research, can, in combination with beneficial bacteria, effectively mitigate the effects of the lack of adequate amount of water in the soil needed by plants for their normal functioning, which is confirmed by the results of other authors [14, 22, 23, 34, 39].

Not only bacteria, but also mycorrhizal and filamentous fungi, as reported by numerous authors [4, 11, 12, 30, 31], and especially their spores, are able to overcome the stress caused, *inter alia*, by a water deficit in the soil and resume biological activity under normal conditions. Therefore, water, alongside other factors, is essential in the behaviour of organisms in a given environment and in their impact on plant life [10, 34, 39]. The results of the study indicate that with optimal irrigation practically all the parameters of plant growth assessment are higher than with the stress of insufficient water supply. However, there are reasons to conclude that the fertilizer Super Fos Dar 40 enriched with bacteria is the factor that, with water deficiency in the soil, will allow plants to live and develop normally, almost as well as when they are irrigated systematically.

5. Conclusions

1. The beneficial influence of microbiologically enriched fertilizers (with bacteria of the genus *Bacillus* and filamentous fungi) is more evident in strawberry plants optimally irrigated than those supplied with 50% less water.
2. With limited irrigation of strawberry plants, only the fertilizer Super Fos Dar 40 combined with beneficial bacteria intensified the vegetative growth of all parts of the plant to a degree similar to that in optimally irrigated plants.

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