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THE INFLUENCE OF MULTIFUNCTIONAL PYROPHYLLITE FERTILIZER (PIROGIPS) ON YIELD OF GARLIC (*ALLIUM SATIVUM*)

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ABSTRACT
The aim of this research was to examine the influence of multifunctional pyrophyllite fertilizer (MPF) PiroGips on the growth of garlic (Allium sativum). A field trial was set up in Banja, Aranđelovac, Serbia with two types of fertilization (control: NPK 8:24:16 25 g/m2, sheep manure 2.5 kg/m2, MPF 15 g/m2, irrigated by water; and experimental: NPK 8:24:16 25 g/m2, sheep manure 2.5 kg/m2, MPF 15 g/m2, fertigated by MPF suspension 5 g/L). At the end of the experiment, the total number of garlic bulbs, total mass and average mass of garlic bulbs were measured. Number of the healthy and undamaged garlic bulbs were same in the both treatments. Total mass and average mass of garlic bulbs 11.14 % were higher compared to the control treatment respectively. This ecological MPF, which improving soil properties, slowing nutrient release, and enhancing plant nutrient uptake efficiency, is composed of pyrophyllite and gypsum from the Parsovići, Konjic, B&H. The sum of secondary macronutrients (CaO, MgO and SO_3) contained in PiroGips is higher than 18% which confirms that this product fulfilled the requirements of EU Regulation 2019/1009. The fertigation with MPF PiroGips have a positive effect on the yield of garlic, especially the mass of the bulb as the most relevant part of the garlic.

1. INTRODUCTION

1.1 Garlic

Garlic (*Allium sativum*) is widely cultivated for its flavorful bulbs, which are not only an essential culinary ingredient but also known for their potential health benefits. Regular consumption of garlic has been linked to a reduced risk of cardiovascular diseases, hypertension, atherosclerosis, hyperlipidemia, and diabetes. The active compound alliin, which is responsible for many of these health-promoting properties, is particularly influenced by the plant's nutrient supply [1]. To achieve high yields and optimal quality in garlic cultivation, it's essential to balance the nutrition of the plant with both macro and microelements. Among the various nutrients garlic requires, sulfur is particularly important. Sulfur plays a crucial role in bulb development and enhances the quality of the garlic, directly impacting the concentration of bioactive compounds like alliin. Research has shown that sulfur fertilization significantly increases alliin levels in garlic cloves, while an excess of nitrogen can negatively affect this concentration [2, 3]. However, garlic's nutrient demands are relatively high compared to other crops. A restricted use of fertilizers, fungicides, and sulfur emissions in many regions has led to sulfur deficiencies, especially in sulfur-hungry crops like garlic. This deficiency can lead to reduced yields and compromised quality. To address this, incorporating sulfur-containing fertilizers into garlic cultivation can help restore the nutrient balance, improving both the quantity and the biochemical quality of the bulbs [4]. In summary, the use of sulfur-based fertilizers is crucial for ensuring garlic's health benefits and maximizing its yield and quality, making it an important factor to consider for successful garlic cultivation.

1.2. Pyrophyllite

Research on pyrophyllite from the Parsovići deposit has shown that the natural mineral pyrophyllite, due to its properties, can be used in agricultural production (animal feed, fertilizers, plant protection, fruit growing, viticulture, vegetable growing, medicinal herbs, forestry, greenhouse production) [5]. Pyrophyllite composite plays an important role in plant growth as it allows cations between layers within the structure to hydrate, leading to the dissolution of various cationic species. As a result, pyrophyllite serves as both a source and a reservoir of ions necessary for plant growth [6]. Pyrophyllite is a phyllosilicate mineral that has been shown to have the ability to trap heavy metals in its internal structure. Thanks to this property, pyrophyllite directly influences the translocation of heavy metals from the soil into the plant, thus preventing their negative impact on plants and, consequently, on human health. In the same way, pyrophyllite prevents the leaching of heavy metals from surface layers of soil into groundwater [7, 8]. Pyrophyllite is a monoclinic mineral from the phyllosilicate group with the chemical formula $Al_2Si_4O_{10}(OH)_2$. It contains electrolytes (sodium, potassium, calcium, magnesium, iron, etc.) and free ions that give it detoxifying and antioxidant properties.

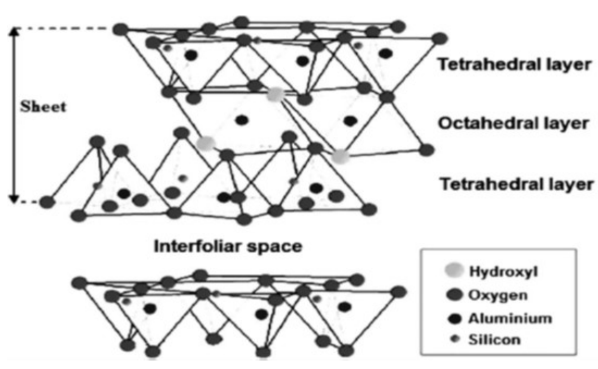

Figure 1. Pyrophyllite structure

The following minerals prevail in pyrophyllite shale: pyrophyllite, sericite, and kaolinite, with certain amounts of quartz, calcite, magnesite, dolomite, illite, and montmorillonite. As an absorptive clay with a combination of ring-shaped tetrahedral molecules, it represents the most suitable geometric form for the intake and/or delivery of nutrients [9].

The chemical composition of pyrophyllite shale is shown in Table 1.

Table 1. Chemical composition of Pyrophyllite shale

Compound	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	Na_2O	FeO	TiO_2	SO_3	P_2O_5	BaO	H_2O
Content (%)	64.15	15.92	6.65	1.57	1.06	0.64	0.31	0.37	<0.17	<0.02	0.18	<0.01	5.18

The pyrophyllite composite contains macro and micro elements (SiO_2, $A_{l2}O_3$, CaO, MgO, Fe_2O_3, K_2O, Na_2O, P_2O_5, TiO_2, Mn, B, Zn, Co, Mo, Cu, S). The pyrophyllite composite is rich in silicon dioxide, and in addition to crystalline SiO_2, it also contains an amorphous form. The amorphous silicon provides the clay particles with an exceptional amount of free surface area for attracting and retaining toxic compounds and offers its nutrients to the soil and plants [10]. Pyrophyllite has multifunctional uses in agriculture, such as a soil conditioner, soil improver, slow-release fertilizer, plant protection agent, and in environmental protection for odor neutralization, leachate and wastewater treatment, remediation, and reclamation of over-exploited agricultural land [11].

2. MATERIALS AND METHODS

2.1. PiroGips

PiroGips is a fertilizer in the form of a composite based on pyrophyllite and gypsum originating from Parsovići, Konjic, Bosnia and Herzegovina. It is classified according to EU Regulation 2019/1009 in category PFC1 as a complex solid inorganic fertilizer containing secondary macronutrients Ca, Mg, and S. According to this regulation, the fertilizer must contain a minimum of 18% compounds (CaO, MgO, and SO_3) [12]. The total of these compounds in the tested fertilizer, PiroGips, was 25.81%. In addition to providing nutrients for plant nutrition with secondary macronutrients (Ca, Mg and S), this fertilizer also contains micronutrients. PiroGips improves the conditions for nutrient utilization, making them available to plants, thus stimulating their growth and development. It also improves the physical, chemical, and microbiological characteristics of the soil. PiroGips is of natural origin, environmentally safe, and suitable for organic production.

2.2. Experimental design

On March 11, 2024, garlic planting was carried out under outdoor conditions in the village of Banja, Aranđelovac, Serbia. The control and experimental onion treatments were planted on an area of 1 m². The row spacing was 30 cm, with a plant-to-plant spacing of 10 cm. Both treatments were fertilized with the same doses of NPK and sheep manure during soil preparation. The control treatment was irrigated with water, while the experimental treatment was fertigated with a PiroGips suspension in water (5 g/L of water) at intervals of 2-3 days, depending on soil moisture.

The experimental soil preparation is shown in Table 2.

Table 2. Soil preparation

Fertilizer	Control treatment	Experimental treatment
NPK (8:24:16), g/m^2	25	25
Sheep manure, kg/m^2	2.5	2.5
PiroGips, g/m^2	15	15

The experimental scheme is shown in Table 3.

Table 3. Experimental scheme

Irrigation/fertigation	Control treatment	Experimental treatment
Water	+	-
PiroGips suspension in water, 5 g/L	-	+

During the experiment, the development of the plants and changes caused by potential diseases were monitored. At the end of the experiment, after harvesting the garlic bulbs, the leaves were removed, and the bulbs were dried outdoors for 24 hours. After drying, the yield of the bulbs was measured on an electronic scale with a measurement accuracy of 1 gram.

3. RESULTS

During the experiment, no significant changes or deviations in plant development or the occurrence of diseases were observed in the control and experimental treatments. Due to the exceptionally high temperatures in the last decade of June and the first half of July, which reached up to 39 °C, leaf drying occurred. As a result, garlic harvesting was carried out on July 18, 2024, about 3-4 weeks earlier than under normal weather conditions. The number of healthy and undamaged garlic bulbs in both treatments was identical, amounting to 19 bulbs. The total mass of the bulbs was 341 g in the control treatment and 379 g in the experimental treatment. The average mass of the garlic bulbs in the control treatment was 17.95 g, while in the experimental treatment it was 19.95 g, which was 2 g or 11.14% higher compared to the control.

Table 4. Mass of the garlic bulbs

Parameter	Control treatment	Experimental treatment
Number of garlic bulbs	19	19
Total mass of the garlic bulbs, g	341	379
Average mass of the garlic bulbs, g	17.95	19.95
Index Control 100%	100.00	111.14

A depiction of the garlic bulbs from both treatments, immediately after drying, is shown in Figure 2.

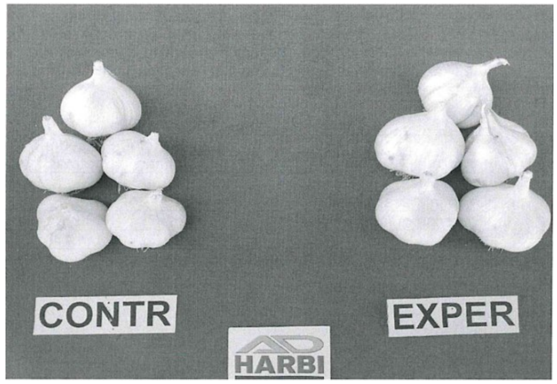

Figure 2. Representation of the garlic bulbs after drying from both treatments

4. CONCLUSION

No significant changes or deviations in the development and occurrence of diseases in garlic plants were observed in the control and experimental treatments. Fertigating the garlic with a suspension of the multifunctional fertilizer PiroGips in water had a positive impact on yield. The average mass of the garlic bulbs in the control treatment was 17.95 g, while in the experimental treatment it was 19.95 g, which was 2 g or 11.14% higher compared to the control treatment. The conducted research should be expanded with analyses of the chemical composition of the garlic bulbs and the content of active compounds in the essential oil to further justify the use of PiroGips in garlic cultivation and other crops for which sulfur is an exceptionally important nutrient.

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