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CHEMICAL STABILITY AND FERTILIZER EFFICIENCY OF BIOGLASS AND BIOCHAR ON ROSE PLANTINGS

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ABSTRACT – Declines in soil quality and low efficiencies of applied fertilizers has limited agricultural productivity worldwide, inducing necessity for sustainable orientated soil amendments. Glass-matrix-based fertilizers are promising "green technologies" thanks to the controlled release of nutrients due to their engineered chemical durability in a wide solubility range. Beside mentioned inorganic soil support, biochar was found to be an effective organic soil amendment that enhances nutrient/water retention as well as microbial activity, making it a promising tool for sustainable agriculture. In this paper, we have tested two possible "green soil amendments": polyphosphate glass (PG) and plum stone biochar (PS) in a 2% citric acid solution, as well as their use as fertilizers on two-year-old rose plantings. The results have shown quick dissolution of PG: nearly 90% for 48 h at 20 ˚C that steady increase up to 97% at the 480 h; under the same operating parameters, 7.6% of PS was dissolved increasing to 8% at final investigated time. Higher temperatures resulted in higher dissolution rate. The data obtained within the scope of this study indicates that tested fertilizers have a positive effect on rose plant growth, not only promoting bud formation but also extending the flowering period of roses.

Keywords: Polyphosphate Glass, Biochar, Durability, Fertilizers, *Lavaglut*.

INTRODUCTION

Plant growth and quality are closely linked to mineral nutrition, which depends on both water and nutrients availability. However, conventional fertilization can pose environmental risks, such as soil nutrient leaching. To minimize these risks, it is crucial to use fertilizers that optimize nutrient uptake while reducing excessive input and environmental impact [1]. Reusing waste materials or industrial by-products as fertilizers can also help address their disposal issues. An ideal fertilizer should release nutrients

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according to plant demand and its phenological stage. Plants regulate nutrient absorption by interacting with their surrounding environment, particularly at the root interface, where they release various organic compounds. These interactions create a dynamic nutrient exchange within the rhizosphere, allowing plants to respond to their environment efficiently [2].

Glass-matrix-based fertilizer has a unique ability to release nutrients only when plants need them. Nutrients contained in its structure become available only in the presence of complexing solutions, which ensures a slow and controlled nutrient release over time, preventing excessive leaching and improving efficiency. Phosphate glasses are particularly interesting due to their low chemical durability, which allows controlled nutrient release. While pure phosphate glasses are highly hygroscopic, their durability can be adjusted from hours to years by modifying their composition. Factors such as the size, charge, and field strength of the modifier cation within the glass matrix also influence their resistance to chemical reactions. Since glass-matrix-based fertilizers do not rely on water solubility for nutrient release, their effectiveness can be assessed using acidic extractants, such as citric acid solution. Citric acid, a common root exudate, helps simulate the plant's natural nutrient uptake process [3-5].

Biochar, a carbon-rich material produced from the thermal decomposition of organic matter in a low-oxygen environment (pyrolysis), has gained attention as a sustainable soil amendment. It offers several benefits to soil health, crop growth, and environmental sustainability. Biochar improves soil structure, increasing aeration, water retention, and nutrient-holding capacity. Sing et al [6] have extracted and statistically analyzed global literature data on biochar influence on different physical, chemical, microbial properties of the soil applied, and crop productivity. It was concluded that application of biochar increased soil pH, cation exchange capacity, and organic carbon by 46%, 20%, and 27%, respectively.

Also, they have confirmed that biochar application reduces bulk densities by 29% and increases soil porosity by 59%. This increase was higher for pyrolytic temperatures higher than 500 °C, while the lower pyrolytic temperatures (< 500 °C) had a greater effect on microbial diversity.

While biochar provides long-term benefits, initial production or purchase costs can be high. However, the application of agricultural waste as a feedstock for biochar production can reduce mentioned expenses. By integrating biochar into farming practices, we can move toward more resilient and sustainable food production systems [7,8].

This study examines the chemical stability of phosphate glass and biochar in a 2% citric acid solution at 20 °C and 50 °C as well as their impact on the bud development of the *Lavaglut* rose variety.

EXPERIMENTAL

In order to obtain phosphate glass (PG), a glass mixture was prepared from the following raw materials: $(NH_4)_2HPO_4$, K_2CO_3, $CaCO_3$, SiO_2, MgO, ZnO and MnO_2. After drying, raw materials were mixed in a mortar, resulting in a homogeneous glass mixture. The glass mixture was heated in a Nabertherm G100/9 electric furnace at 1230 °C for 1

h. The melted glass mixture was poured onto a steel plate and cooled in air. PG was ground in an agate mortar and stored in a desiccator.

Plum stones were obtained from the local fruit processing company from Serbia, where they were considered as a waste. The stones were washed by tap water, dried at room temperature, ground using a Siebtechnik – TS250 vibrating disk mill (Siebtechnik GmbH, Germany), and then sieved to fraction between 0.1 to 0.5 mm. After grinding, the plum stones were pyrolyzed at heating rate of 10 °C/min from room temperature up to 500 °C, when they were kept for 90 min, in a Nabertherm 1300 muffle furnace (Nabertherm, Germany).

The chemical stability of PG and PS in a 2% citric acid solution was tested at a temperature of 20 °C. One gram of each material (PG-granulation 0.1-0.3 mm or PS-granulation 0.1-0.5 mm) was placed in plastic containers, followed by the addition of 50 ml of citric acid solution. The containers were then placed in a thermal bath, preheated desired temperature.

After a specified experimental period under isothermal conditions, the containers were removed, and the solid and liquid phases were separated by filtration. The obtained solutions were analyzed for the content of present ions, and after drying the solid phase, the dissolved mass of PG or PS was determined.

The chemical composition of PG and PS and the solutions after dissolution in 2% solution of citric acid were analyzed using gravimetric and spectroscopic methods, including AAS with a PERKIN ELMER AAnalyst 300 instrument and UV/VIS spectroscopy with a Specol Analytik JENA 1300 spectrophotometer.

The *Lavaglut* variety was produced in a two-year cycle through grafting in July 2022. The effect of applying phosphate glass and biochar was monitored on *Lavaglut* rose variety with addition of PG and PS as eco-fertilizers starting in February 15, 2023. The agrochemical analysis of the soil showed that it had a neutral to slightly acidic reaction.

The soil was characterized by an available nitrogen content of 32.9 mg/kg, a low available phosphorus content, and was well-supplied with potassium (22.4 mg/kg). This type of soil is suitable for the production of rose seedlings [9]. The effect of PG on roses was tested at three different doses (1, 2 and 3 g/rose plant), while the effect of PS was examined at two doses (5 and 10 g/rose plant).

Throughout the vegetative cycle, various growth and development parameters of the roses were monitored. The data were analyzed using one-way analysis of variance (ANOVA) with R software, version 3.6.0. Statistical significance between individual treatments was tested using the Tukey HSD test, at a significance level of 0.05. Throughout the research period, six treatments were applied for disease and pest control.

RESULTS AND DISCUSSION

The chemical compositions of PG and PS created and used in described experiments are presented in Table 1. These analysis relate to the main mineral components present in the samples structure since the most of the biochar structure relates to the carbon element (more than 70%), and approximately 2% of dry mass of PS represents mineral ash content.

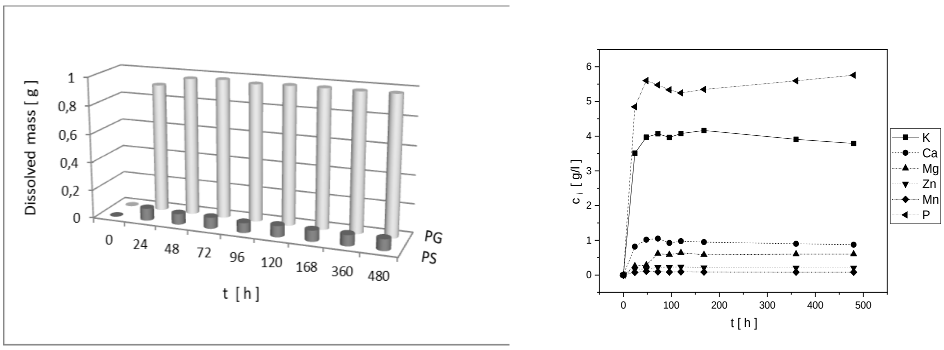
This material also contains app. 1.62% of nitrogen, which is also beneficial for the plant growth [10]. Beside the oxides mentioned in Table 1, sample PS contains 0.021% of Fe_2O_3, which was not present in the sample PG.

Table 1 Chemical composition of phosphate glass and biochar

[mol%]	P_2O_5	SiO_2	K_2O	MgO	CaO	ZnO	MnO
PG	45.4	3.1	25.6	9.3	14.5	1.2	0.9
PS	0.406	0.105	0.795	0.356	0.350	0.008	0.009

Figure 1 (a) shows the dissolved masses of PG and PS in a 2% citric acid solution at 20 °C for different experimental times. Over a 24-hour period, approximately 8% of the biochar dissolves, whereas around 90% of the glass dissolves within the same timeframe. The result of PS solubility is related to the total organic carbon (TOC) release as well as leaching of the mineral components. After 48 h, 97% of PG and 7.6% of PS were dissolved in the citric acid solution at 20 °C. At extended dissolution times (at 20 °C) the dissolved mass of PS remains constant at approximately 8%, thanks to the stable, mostly aromatic, matrix of biochar that cannot be further dissolved. In contrast, PG continues to dissolve as the dissolution time increases. After 480 h, around 98% of the initial glass mass was dissolved. The higher temperature (50 °C) induced higher dissolution of the samples; for example, for the same period of time (48 h), dissolved mass of glass was 98% [11] for PG and 8.7% for PS (data not shown).

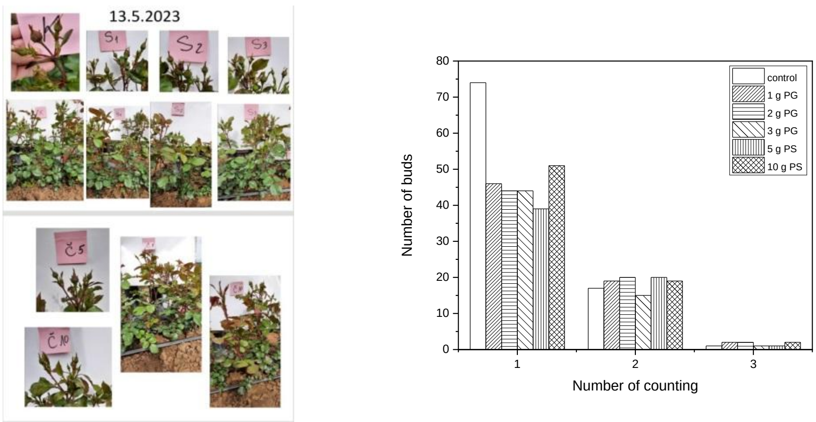
Figure 1 (b) illustrates the ion concentrations in the solutions following the dissolution of PG in a 2% citric acid solution. The results of PS dissolution (data not shown) indicates highest dissolution of potassium (starting from 81 to 112 mg/l, after 24 h and 480 h, respectively. The results also reveal that the element concentrations in the PG solution are approximately 200 times higher than those in the PS solution, which was expectable because the much lower mineral content of the PS compared to PG.



a) b)

Figure 1 Dissolved mass of PG and PS in 2% citric acid solution at 20 °C (a) and Concentrations of elements in solutions after dissolving PG in 2% citric acid solution (b)

The bud count of rose seedlings was conducted three times, spanning from May to the mid-September. In the first count (the appearance of rose buds during the first counting is shown in Figure 2(a)), conducted after 3 months from fertilizer application, the average number of buds ranged from 39 (5 g PS) to 74 (control). The application of PG and a higher tested dose of PS (10 g) had a statistically significant effect on the formation of a greater average number of flower buds compared to the application of 5 g of PS. The average number of formed buds ranged from 44 to 46 with the application of PG, while with PS it reached 51. The highest effect on the average bud count (51 buds) was observed with 10 g of PS, which was statistically significantly higher than in other tested variants but still lower than the control variant (74 buds). This can be attributed to the fact that formed plants first absorb nutrients from the soil before utilizing the fertilizer. In the second count, conducted 5 months after the fertilizer application, a positive effect was observed with the application of 2 g of PG and 5 g of PS. This resulted in statistically significantly higher bud count than in the control, as well as in variants with the lowest and highest tested doses of PG (variants 1 g and 3 g) and variant 10 g of the PS. In the third count (7 months after fertilization), the control variant's average bud count did not differ statistically significantly from variants 3 g PG and 5 g PS. However, it was statistically significantly lower than in variants 1 g PG, 2 g PG, and 10 g PS, indicating a positive effect of 1 g and 2 g of PG and 10 g of PS on bud formation. No statistically significant differences were observed in the average bud count among variants 1 g PG, 2 g PG, and 10 g PS. Furthermore, during the second and third counts, most tested fertilizer doses resulted in a higher bud count compared to the control samples. These findings suggest that phosphate glass and biochar not only promote bud formation but also extend the flowering period of roses. The average number of buds for all three counts is shown in the Figure 2(b).



a) b)

Figure 2 The appearance of rose buds (S-polyphosphate glass; Č- plum stone biochar) (a); Average number of buds (b).

CONCLUSION

This study presents the results of the chemical stability of phosphate glass and biochar in a 2% citric acid solution, along with their effects as fertilizers on the growth and development of *Lavaglut* roses. Over the longest experimental period, approximately 98% of the glass dissolved in acid solution, while around 8% of the biochar dissolved in the same timeframe. The ion concentrations in the solutions were about 200 times higher in the glass solution compared to the biochar solution. The average number of buds and flowers varied depending on the counting time. The most significant increase in the number of buds and flowers occurred in July (five months after fertilization) when the plants were in full bloom, where the effects of phosphate glass and biochar application reached their peak, with doses of phosphate glass of 3 g per rose plant and biochar of 10 g per rose plant, respectively. These results also confirmed that aside from positive effects on the increase of average number of flowers, there is no toxicity of these fertilizers on the investigated plant growth. The rise in the average number of buds formed during the rose growing season helps sustain flower yield throughout the entire season. Further experiments should include examination of synergistic effect of both fertilizers in the same trial.

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