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APPLICATION OF SUSTAINABLE FERTILIZERS: BIOCHAR AND PHOSPHATE GLASS EFFECTS AT ROSE FLOWERING

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Abstract:

Controlled release fertilizers (CRF) provide nutrients that dissolve gradually, remaining available to plants longer than conventional fertilizers. This study investigates the influence of phosphate glass and biochar, as prospective controlled-release fertilizers, on the growth and development of rose seedlings. Biochar is the product of thermochemical conversion of biomass, where organic substances are thermally broken down at specific process parameters, in a reduced oxygen atmosphere. Phosphate glass (45.4P₂O₅·25.6K₂O·14.5CaO·3.1SiO₂·9.3MgO·1.2ZnO·0.9MnO) was synthesized from reagent-grade materials by melting at 1230 °C for 1 h in a porcelain crucible and quenching on steel. Different dosages of plum stone biochar (PS) and phosphate glass (PG) were tested on rose plantings. The addition of PS and PG had no significant influence on the number of branches, but higher doses (3 g of PG and 10 g of PS) favored flower formation. Chemical analysis at the end of the cycle showed increased phosphorus and manganese in all samples, higher zinc with 2 g PG, and elevated calcium in all variants. Overall, addition of PG and PSB to the soil samples improved rose growth.

Key words: biochar, phosphate glass, CR fertilizers, roses.

INTRODUCTION

Flower production, as a specific form of agricultural production, is the most dynamic industry in the world and plays a significant role in economic and social development of any country. As a highly profitable sector, flower production is constantly growing, with an annual turnover exceeding 300 billion euros. Flowers have become the most fashionable consumer good, with great development potential, since the demand increases year by year (15–20% annually) alongside the rise in living standards. It is an industry that is „economically without borders” highly competitive and highly risky. It can be organized both in open fields and in protected environments. The flower industry is characterized by high investments, advanced technology, high returns, but also high risks [1-3].

In the era of significant environment pollution and nonrenewable resources depleting, researchers are constantly exploring for „new” fertilizers that ensure more effective action on crop growth, while having less impact on the environment. Biochar, a carbon-rich material produced by pyrolysis of biomass, has emerged as a sustainable soil amendment due to its multiple agronomic and environmental benefits. Its highly porous structure enhances soil aeration, water retention, liming potential, cation exchange capacity, but also brings significant content of available nutrients necessary for the plant growth. In addition, biochar addition often raises soil pH in acidic soils, creating more favorable conditions for plant growth [4, 5]. Biochar composition and structure has been proven as a valuable habitat for beneficial soil microorganisms, which further support nutrient cycling and plant health [6]. At the same time, many investigations have demonstrated ability of biochar to reduce the level of heavy metal contamination in soil and water, resulting in stimulated responses from microbial populations [7]. Many investigations worldwide are conducted in order to assess the benefits of biochar addition into the growing media of various horticultural and ornamental crops, [8], but all of them induce necessity of good biochar characterization and proper dosage onto the soil.

Agriglasses have in recent years been offered (and applied) as an alternative in flower production, as they have a positive effect both on the natural environment and on yields [9]. Their use provides the necessary nutrients in sufficient quantities that are easily accessible; they do not leach into deeper soil layers, since the unused portion of the glass remains in the upper layers of the soil, which also makes them environmentally justified. Agriglasses (glassy fertilizers) based on phosphate glasses are classified as a group of controlled-release (CR) fertilizers. Glassy fertilizers possess bioactivity, meaning they have the ability to participate in the biological processes of living organisms [10,11]. Phosphate glasses generally exhibit low chemical stability in aqueous solutions. The dissolution of the glass depends on the glass network itself as well as external factors, such as the condition of the glass surface, the ratio of glass surface area to solvent volume, saturation effects, the type of solvent, solvent flow rate, and others. Understanding the dissolution process and the rate of ion release from phosphate glasses in aqueous solutions is very important from the perspective of engineering material design [12]. The solubility of phosphate glasses can be tailored to specific plant types and soil conditions by modifying the chemical composition and granulation of the glass. During the plant growth cycle, the components released from the glass are consumed intensively, and their levels in the vicinity of the glass granules decrease, which increases the driving force of dissolution and intensifies the dissolution process. Conversely, at the end of the growth cycle, the consumption of the released components decreases, and their concentration around the glass granules increases, causing the driving force of dissolution to decrease and slowing down the glass dissolution process in the soil. Additionally, soil temperature and moisture have a significant effect on the glass dissolution process [13,14].

In this paper, we have investigated the effect of two "sustainable" fertilizers, agriglass and biochar, onto the rose flowering, in order to examine their possible effects and direct our future work. In the same time, chemical analyses of harvested rose plant biomass were performed in order to quantify the content of nutritional elements most important in the plant physiology: P, Zn, Ca and Mn.

MATERIAL AND METHODS

Phosphate glass (PG) and plum stone biochar (PS) samples were synthesized as previously described in [15]. The chemical durability of PG and PS was assessed in 2% citric acid solution at 20 °C by the same methodology adopted from [15]. The chemical composition of PG, PS, and the post-dissolution solutions was examined using gravimetric methods and spectroscopic techniques, including atomic absorption spectrometry (AAS; PERKIN ELMER AAnalyst 300) and UV-Vis spectrophotometry (Specol Analytik JENA 1300).

The *Lavaglut* rose cultivar was propagated via grafting in July 2022 within a two-year production cycle. The agronomic performance of PG and PS as eco-fertilizers was investigated beginning from February 15, 2023. Soil analysis revealed a neutral to slightly acidic reaction, an available nitrogen concentration of 32.9 mg/kg, low phosphorus availability, and sufficient potassium supply (22.4 mg/kg), conditions favorable for rose seedling cultivation [9]. PG was applied at three rates (1, 2, and 3 g/plant), whereas PS was tested at two rates (5 and 10 g/plant). Plant growth and developmental parameters were systematically recorded throughout the vegetative cycle. The counting of open flowers was conducted three times from late May to mid-September.

In mid-September, composite samples of aboveground roses biomass were collected from all experimental variants for chemical analysis of the rose plant material. The biomass (rose leaves with twigs) was dried in an oven at 60 °C and subsequently ground to achieve sample homogenization. The plant material was digested with concentrated HNO₃, followed by oxidation with concentrated HClO₄.

Elemental contents (K, Ca, Mg, Zn, Mn, and Fe) were determined by atomic absorption spectrophotometry using a Perkin Elmer 703 instrument, while phosphorus was quantified spectrophotometrically after extraction with isoamyl alcohol on a Spekol 1300 Jena spectrophotometer. Data analysis was conducted by one-way ANOVA (R software, v.3.6.0), with pairwise comparisons performed using Tukey's HSD test at a significance level of $p <$

0.05. Over the study period, six phytosanitary treatments were implemented to control diseases and pests.

RESULTS AND DISCUSSION

The chemical compositions of PS and PG employed in the experiments are summarized in Figure 1. The presented analyses primarily reflect the dominant mineral constituents within the samples, as the biochar matrix (Figure 1a) is largely carbonaceous (>70%), with mineral ash accounting for approximately 2% of the PS dry mass. In addition, PS biochar contains about 1.62% of nitrogen, an element of agronomic relevance due to its positive effect on plant growth [7]. Apart from the oxides presented in Figure 1, the PS sample also exhibited a minor Fe₂O₃ fraction (0.021%), which was absent in PG (Figure 1b).

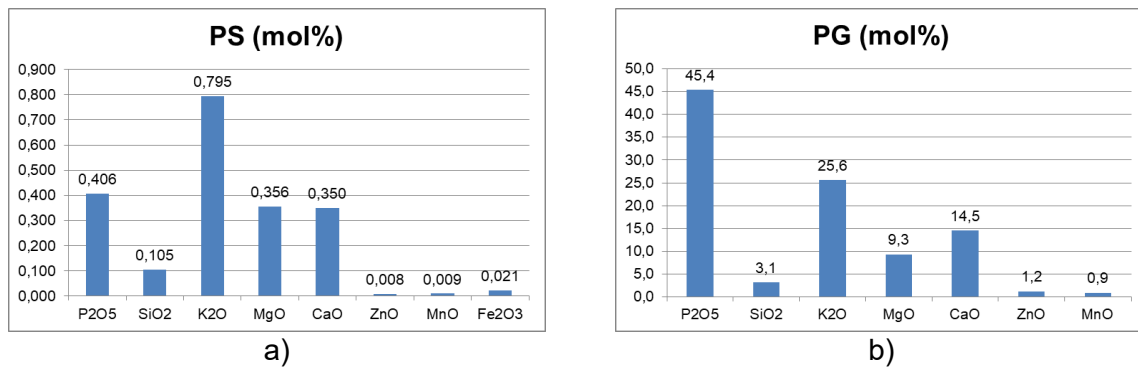


Fig. 1. Chemical composition: a) biochar and b) phosphate glass.

The investigated phosphate glass exhibits markedly lower chemical stability in citric acid solution compared to biochar. Over the longest experimental duration (480 h), approximately 98% of the glass dissolves, whereas only about 8% of the biochar undergoes dissolution within the same time frame. Figure 2 presents the ion concentrations in the solutions at various experimental intervals for biochar (Figure 2a) and for glass (Figure 2b). The ion concentrations are nearly 200-fold higher in the solutions resulting from glass dissolution than in those obtained from biochar.

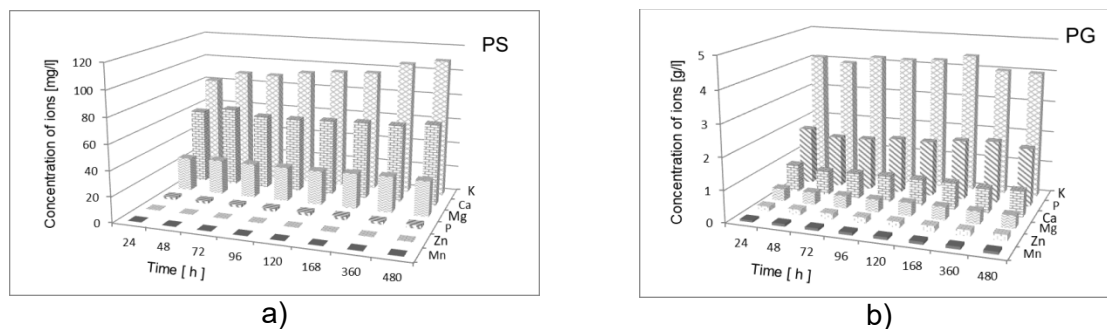


Fig. 2. The ion concentrations in the solutions: a) biochar and b) phosphate glass.

To evaluate the effects of phosphate glass and biochar as eco-fertilizers, the concentrations of elements absorbed by plants were determined in the plant material collected at the end of the vegetation period.

The results of the chemical analysis (Table 1) should be interpreted with caution due to the short duration of the study. These values are to be considered relative, as longer-term investigations (multi-year trials) are required to obtain reliable data. Only through extended experimentation can the consistent effects of phosphate glass and biochar application be confirmed, thereby providing a more accurate assessment of their agronomic potential.

Phosphorus is essential for the formation of cell membranes, carbohydrate metabolism, protein synthesis, photosynthesis, and the storage and transfer of energy. As emphasized by Mišić

[16], it strongly influences flower formation and plant growth. The application of phosphate glass and biochar (Table 1) resulted in an increase in phosphorus (P) content in all experimental variants compared to the control.

Table 1. Macro- and microelement contents (mg/kg) in the analyzed rose plant material.

Treatment variants	Ions [mg/kg]						
	P	K	Ca	Mg	Zn	Mn	Fe
Control	1929.91	9224.77	10249.75	3283.25	33.99	33.25	208.24
5 g PS	1970.77	7552.78	11749.40	3204.16	28.49	76.75	196.49
10 g PS	2630.07	8499.16	11498.85	3178.85	30.24	52.49	185.98
1 g PG	2065.71	8976.16	10251.30	3050.39	31.75	37.50	142.77
2 g PG	2131.68	8873.82	9748.72	3178.74	34.25	39.49	145.98
3 g PG	2003.38	7997.15	9746.50	3203.02	29.74	49.98	203.42

Manganese (Mn) is an important component of several enzymes. It also participates in various redox processes and contributes to plant resistance against abiotic and biotic stresses. The results obtained (Table 1) indicate that the content of this element was significantly higher in variants treated with all doses of phosphate glass and both doses of biochar compared to the control. The excess manganese can inhibit chlorophyll biosynthesis in leaves, which is reflected in the reduced Fe content in the plant material, showing a complete inverse correlation with Mn levels (higher Mn – lower Fe, and vice versa) [17].

Zinc (Zn), as an essential biogenic element, is involved in numerous plant functions and has been identified in more than 80 proteins [16]. This element is required for the synthesis of the amino acid tryptophan, which participates in auxin biosynthesis. The highest zinc content (Table 1) was recorded in the variant treated with 2 g of phosphate glass (34.25 mg/kg).

The calcium (Ca) ion content (Table 1), which serves as an important intracellular signal transducer and influences various developmental processes in plants, was increased compared to the control, particularly in the variants treated with both doses of biochar. Similar trend of elevated level of Ca content (but also decreased level of K) in rose biomass was observed by Fascella et al.[8] who investigated addition of biochar made from conifer wood as a substrate component for growing *Rosa rugosa* plants. These authors have also confirmed that in biochar applied pots plant leaves has a higher photosynthesis rate.

Regarding the contents of potassium (K), magnesium (Mg), and iron (Fe) in the plant material (Table 1), their highest levels were recorded in the control variant and showed correlations with the contents of other elements (higher calcium–lower magnesium, and vice versa).

The influence of various macro- and microelements on the development of rose seedlings can be assessed by observing the number of open flowers. Phosphorus is essential for the development of flower buds and the formation of flowers, and its deficiency reduces flower production. Calcium is important for the stability of cell membranes and intracellular signaling, affecting flower development and bud resilience. Zinc and manganese are critical for enzymatic processes and hormone-related pathways associated with flowering, such as auxin and gibberellin synthesis [18].

The counting of open flowers was conducted three times from late May to mid-September. Table 2 presents the results of all three counts of open rose flowers for all experimental variants.

Table 2. Mean number of open flowers for each experimental variant

Counting	Control	PS		PG		
		5 g	10 g	1 g	2 g	3 g
I	19c	19c	31a	19c	23b	18,5c
II	5c	3d	7a	3d	6b	7a
III	4a	2c	3b	2c	3b	4a

Different letters in the columns indicate a statistically significant difference between treatments at the 0.05 significance level.

The average number of flowers in the first count ranged from 19 (control, PS-5 g and PG-1 g), while the highest average number of flowers was recorded in variant PS-10 g. The average number of open flowers in the variant treated with 2 g of PG (23) was statistically significantly lower only compared to the average number of open flowers in variant PS-10 g, and statistically significantly higher than the average number of buds observed in all other variants.

During the second count, a positive effect of higher doses of PG (2 g and 3 g) as well as the higher dose of PS (10 g) on the average number of flowers formed was observed, which was statistically significantly higher compared to the average number of flowers in the control, variant PG-1 g, and variant PS-5 g. Furthermore, the application of 3 g of PG resulted in a statistically significant increase in the average number of flowers, even though it did not affect the average number of buds.

A similar trend was observed with biochar application, where the higher dose statistically significantly increased the average number of flowers compared to the lower dose.

During the third count, at the end of the growing season (mid-September), the average number of flowers was lower compared to the first and second counts. This is understandable, as roses enter a period of vegetative dormancy at the beginning of autumn. The highest average number of flowers (four) was recorded in the control variant and in the variant with the maximum tested dose of phosphate glass (3 g), and it was statistically significantly higher than the average number of flowers observed in all other experimental variants.

Plants primarily absorb available macro- and microelements from the soil, and when these sources are depleted, they begin to take up the same elements from applied fertilizers. Based on the results presented in Tables 1 and 2, it can be concluded that roses in all experimental variants absorbed higher amounts of phosphorus compared to the control, which positively affected the number of open flowers. Additionally, the amount of calcium absorbed by plants treated with phosphate glass was significantly higher than in the control, which may also contribute to an increased number of flowers. The manganese content was elevated in all plants treated with PG and PS compared to the control [18].

CONCLUSION

Besides bringing nutrients from depleting non-renewable sources, traditional water-soluble fertilizers may cause variety of environmental problems at the same time. Many papers have confirmed beneficial effects of new sort of slow-releasing fertilizers, which are able to improve the soil structure without its degradation, but also to enrich it by bringing essential nutrients necessary for plant growth. In this paper, we have confirmed beneficial effects of two environmental friendly fertilizers onto rose flowering: agriglass and biochar, both made in our laboratories. It is confirmed that, besides improving the ornamental quality of the roses grown (e.g. number of flowers), synthesized fertilizers brought essential microelements into the plant structure (P, Zn, Ca and Mn) improving overall plant health.

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