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WASTEWATER USE IN GROWING ORNAMENTAL PLANTS IN AZERBAIJAN

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SUMMARY

The growth and development evaluation of the ornamental plant *Goldmoss stonecrop* (*Sedum acre* L.) applied with different doses of sewage sludge was the focus of this study. *Sedum acre* growing for two months continued in vessels containing 500 g of nutrient soil in the greenhouse. Chorological analysis showed the *Crassulaceae* species distribution covered three different areas of the Irano-Turanian Province. The experimental technique also met the requirements for the vegetation experiment. During the growing season, the morphological parameters of plants and the chlorophyll content in the *Sedum acre* L. leaves succeeded detection. The application of municipal waste developed the variations in ash content of the soil and positively affected the phosphorus and potassium contents. The work established an observable relationship between an increased dose of sewage sludge and the variations in acidity of the peat soil. In *Sedum acre* L., the obtained maximum plant biomass emerged with the recommended dose of sewage sludge and fertilization added to the soil.

Keywords: *Goldmoss stonecrop* (*S. acre* L.), ornamental plant, sewage sludge, leaf biomass, morphological indicators, flowering phase

Key findings: In *Goldmoss stonecrop* (*S. acre* L.), it is advisable to use fertilization in the soil. The phenological observations of *Sedum acre* L.'s different vegetative stages (flower bud swelling, flowering, fruit setting, and fruit ripening) emerge as first-time research, considering them as innovative from an environmental viewpoint.

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INTRODUCTION

Plants, like other living organisms on this planet, also need water for their survival and various functions. Water regulates the temperature in crop plants, cooling the plants through evaporation from the leaf surface and green body structure, eventually prolonging the photosynthetic activity period. The development of parks and gardens in cities led to the conservation of lands and their culturalization.

In urban areas, soil acts as the primary framework and plays a major role in regulating surface runoff and groundwater levels while protecting the soil layers and developing biochemical processes. Waste disposal is one of the main environmental problems of modern society (Nolasco *et al.*, 2023; AzStat, 2024). A significant share of wastes comprised wastewater from cities and industrial enterprises entering the treatment plants. As a result, the sludge accumulates at wastewater treatment plants, which are wastes from mechanical, biological, and physicochemical treatments of the surface and groundwater. The composition of the resulting sediments resulted from their purification and the content of pollutants. The sediments contain vast amounts of organic matter, nitrogen (N), phosphorus (P), potassium (K), and various microelements (Babaev *et al.*, 2017; FAO, 2020). In applied wastewaters, the basic nutrients could be greater than in farmyard manure (Bojinov *et al*., 2022).

The sludge disposal wastewater is the placement of sediments on filtration fields, sludge banks, and dumps, where they accumulate in large volumes in Azerbaijan. Given the limited facility for storing sediments, the problem of their placement arises. If stored improperly, a possibility exists of pollutants entering natural bodies of water and groundwater, soils, and plant communities. Disposing of sewage sludge by incineration is an environmentally harmful process (Hasanova and Asgarova, 2021a; Kazeev and Kolesnikov, 2012). By disposing this way, the release of benzopyrene, dioxins, furans, and some other substances polluting the environment may occur. Waste disposal can succeed by using sewage sludge as fillers in the production of concrete, building ceramics, glass, pigments, and paints, and also using sewage sludge to produce biogas and hydrocarbons (Kulik *et al*., 2021; Hasanova *et al*., 2021b). All these processes involve the use of high-tech equipment and additional costs (within reasonable limits).

The most promising use of sediment wastewater can be making it as fertilizer in the agriculture sector (Nasirova *et al*., 2022). As an organic-mineral fertilizer, precipitation has a positive effect on the fertility, structure, and composition of the soil. Furthermore, an increase in the organic matter content, preservation of moisture and aggregation, and prevention of soil erosion will exist (National Enc., 2018). Evidence of a decline in soil density and an increase in its overall porosity, moisture capacity, and the content of water-resistant aggregates prevails. An observation showed the precipitation to the soil has a prolonged effect, persisting for several subsequent years.

The humus formation gets enhanced by the addition of sewage sludge. Regarding dry matter and basic nutrients, sewage sludge is not inferior to cattle bedding manure. Several studies also authenticated that crop productivity increased with rainfall on the soil (Moyin-Jesu, 2007; Niu and Cabrera, 2023). The sewage sludge as a fertilizer revealed records of positive effects on the bioproductivity and biological activities of the soil. An experience appeared in using sewage sludge in urban landscaping, with useful effects noted by applying it to ornamental crops. However, in addition to impurities of organic and mineral substances, sewage sludge also contains general toxic, toxicogenetic, embryotoxic, and carcinogenic concentrations (Petrova, 2022). The precipitation wastewater contains heavy metals, such as chromium, cadmium, mercury, copper, lead, cobalt, zinc, and molybdenum. Likewise, it has various toxic substances from the biological objects, i.e., bacteria, protozoa, helminths, and viruses.

Among the organic compounds, the most common are organic halogens, alkylbenzenesulfonates, nonylphenols, diethylhexyl phthalate, and polyaromatic hydrocarbons. The harmful and toxic substances limit the use of sewage sludge as fertilizer, since these compounds ultimately enter the environment. Therefore, the use of sewage sludge requires regulation by legal documents. To date, some advanced processes have been developed to prevent the entry of heavy metals into the natural environment. One of the methods for reducing the concentration of heavy metals is to create the mixture of sewage sludge with components that are neutral in this regard, such as straw, sawdust, manure, peat, and tree bark. Composting sewage sludge with various materials is one of the ways to prepare sludge for use and to reduce the toxic substances, as per the established standards (FAO, 2020).

Based on experimental data, environmentally safe use has been progressive for using sewage sludge, increasing productivity, and improving the agrochemical parameters of the soil. In the soil and crop products, the concentrations of heavy metals remained within acceptable limits. It has been notable that crops' yield can escalate without compromising the crop quality by using sewage sludge. However, by applying sewage sludge to crop plants, heavy metals may accumulate in the soil and crop products. In the long-term experiments (five rotations of a seven-field crop rotation), it has been evident that the systematic application of sewage sludge enhances the content of gross forms of heavy metals in soddy-podzolic soil by 1.1 to 2.7 times and acid-soluble and mobile forms by 2.1 to 6 times (Bunyatova *et al.*, 2025). By using sewage sludge, the concentration of heavy metals increased in the soil, leading to their accumulation in crop plants.

Chemical treatment and composting techniques have emerged to enhance the safety and agronomic values of waste. Sediments of wastewater have also become suggestions for fertilizing non-food crops, such as lawns, flower beds, and nurseries. A positive effect of precipitation on the growth of ornamental plants was prominent, as it increased the growth rate of salvia, alternanthera, lobelia, cineraria, and marigolds by 30%–88% (Babaev *et al.*, 2017). The feasibility of using precipitation has succeeded in establishing wastewater application under perennial grasses (red fescue, perennial ryegrass, and meadow bluegrass) in landscaping urban areas. Therefore, a problem prevails with using sewage sludge associated with the establishment of optimal, environmentally safe doses for growing plants. The presented study aimed to evaluate the growth and development of Goldmoss stonecrop (*Sedum acre* L.) applied with different doses of sewage sludge.

MATERIALS AND METHODS

The promising experiment transpired in greenhouses in the Lesser Caucasus regions with some characteristic areas of Azerbaijan. The feasibility of using sewage sludge for landscaping urban areas is apparent from environmental and economic viewpoints; however, the development of favorable conditions for growing ornamental plants requires clarification. This study's objectives comprised a) determination of plant biomass with the application of various doses of municipal waste, b) assessment of plant development based on morphological traits, and c) conducting the agrochemical analysis of studied soils. The assessment of optimal ratios of waste with acid peat and the plants' development traits proceeded under the growing conditions in vessels with a capacity of 500 g, in threefold repetitions.

Municipal waste was the chief material used to prepare the soil, i.e., sewage sludge from municipal wastewater treatment plants, coal ash thermal power plants, and the acidic high-moor peat (Talibi and Hasanova, 2022). The studied sewage sludge contains nutritional elements, viz., P_2O_5 (365.5 mg/kg), K_2O (155.3 mg/kg), and N (84.65 mg/kg), with a neutral reaction of the environment (pH = 7.1). The heavy metal content does not exceed the standard. The experiment examined the recommended ratio of waste to peat (1:0.25) and the ratio with an increased dose of waste (1:0.5). The option considering the use of high-moor peat served as the comparison. This soil's usage is traditionally for growing ornamental plants in greenhouses. The study based on

Table 1. Agrochemical indicators of the soils at the Ganja-Kazakh Region.

Options	Organic matter (%)	Ash content (%)	pH
Control	93.66	6.34	7.0
Control + fertilization	90.11	9.89	6.9
Ground 1:0.25	85.46	14.55	6.17
Ground 1:0.25 + fertilization	81.07	18.93	7.8
Ground 1:0.5	76.28	23.72	7.3
Ground 1:0.5 + fertilization	80.83	19.17	7.8

fertilizing values of waste occurred against the background of fertilizing with complete mineral fertilizer. Plants' fertilization with azophoska had a dose of 3 g/l with a working solution consumption of 100 ml per vessel (Rowell, 1999). Agrochemical indicators of the studied soils also bore scrutiny, with the experimental scheme presented in Table 1. *Sedum acre* L. was the choice for cultivation in the growing experiment. *Sedum acre* is an annual, fast-growing plant with original inflorescences. It is effective in group plantings against the lawn, in bouquets, and in compositions. Ornamental plants prefer loose, fertile soils and sunny areas but sheltered from the wind. During dry periods, it requires abundant watering. The plants, sown as seedlings, proceeded to their planting in pots with the prepared soil. In the experiment, morphometric parameters' measurement occurred in dynamics. At the end of the experiment, the mass determination of the aboveground plant parts also succeeded. The measurement of the chlorophyll content (chlorophyll quantity index) in plants used the N tester device. The device uses a photometric diagnostic method, which allows it to determine the nitrogen supply of plants.

RESULTS AND DISCUSSION

The results revealed that the increased proportion of waste in the soil did not show a significant increase in plant yield in the *Sedum acre* L. Therefore, the use of such soil for growing ornamental plants is advisable with fertilization. Past studies also enunciated that an enhanced proportion of waste in the soil showed a nonsignificant increase in plant yield (Hasanova *et al*., 2021a; Macnunlu *et al*., 2025).

After harvesting the *Sedum acre* plants, an agrochemical analysis of the soil continued (Table 1). The addition of sewage sludge and ash to the test soil significantly altered the acidity toward the slightly alkaline side (the pH of 6.29 in the control and pH of 8.21 in the variant with the maximum dose of waste). The ash content also increased compared with the control, more than three times in the soil variant with a ratio (1:0.5) without fertilizing. The organic matter content rose proportionally to the ash content's decrease in the soil. The addition of organic waste showed a positive effect on the content of nutrients. Rainfall application with wastewater significantly enriched the content of available phosphorus, and the P_2O_5 value enhanced more than 10 times compared with the control (Figure 1).

Doubling the waste dose did not lead to a substantial increase in the phosphate level; however, NPK fertilization had a noticeable effect on the available phosphorus (Rayner *et al*., 2016). The influence of municipal waste on the available potassium in the soil was more significant and depended upon the precipitation of wastewater ash in the soil (Figure 2). Despite the rise in phosphorus and potassium levels, a nonsignificant positive effect appeared on plant growth by adding sewage sludge to peat (Figure 3). The plant weight with the recommended dose of sewage sludge was at the level of the control variant. However, in all the variants, the noteworthy increase in biomass was affirmative only by fertilizing with NPK. According to the results, the NCP_{05} was 3.2402. The maximum biomass obtained for amaranth occurred when applying the recommended dose of waste (1:0.25) together with NPK fertilization (Mammadova *et al*., 2024). A further increase in the waste

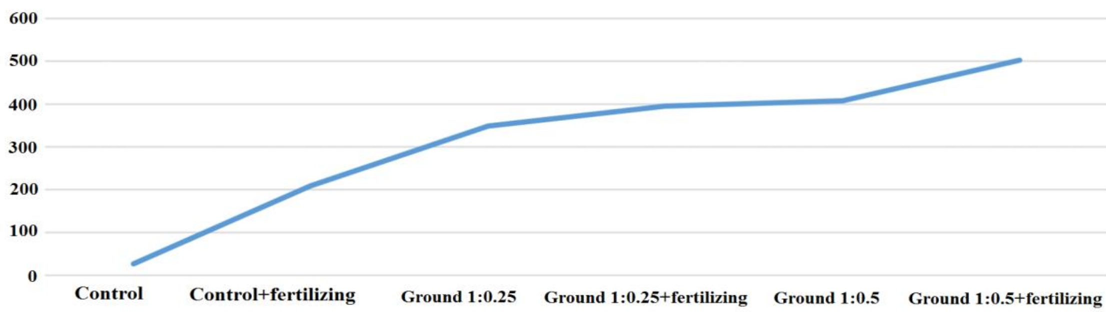

Figure 1. Mobile phosphorus content (mg/kg) in the soil.

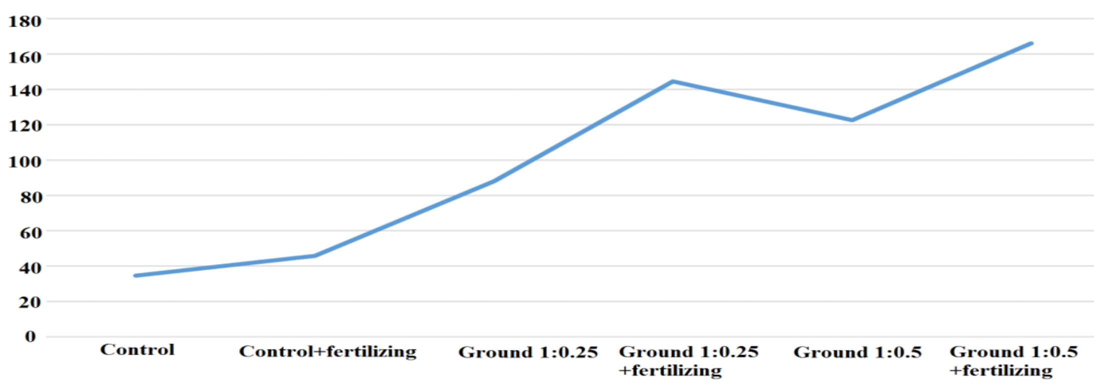

Figure 2. Available potassium content (mg/kg).

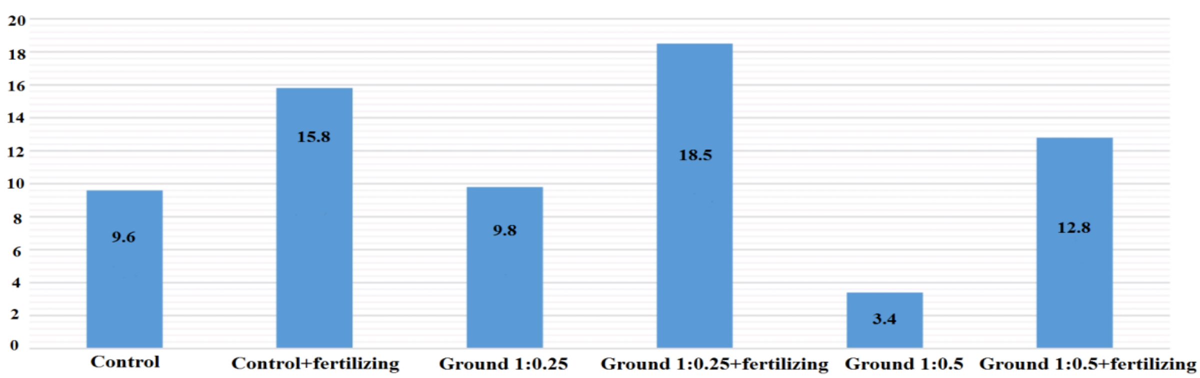

Figure 3. Plant weight (g/vessel) in the experiment.

(1:0.5) led to plant suppression and eventually a decline in plant biomass. The dynamics of plant development based on morphological parameters are available in Table 2 and Figure 4. In general, the morphological development of the plants corresponds to the pattern noted in the analysis of plant biomass at the end of the growing season. Plants grown on techno-soil without fertilizing (variants soil 1: 0.25 and soil 1: 0.5) displayed the signs of depression, probably caused by a lack of available nitrogen (Hasanova and Mammadova, 2023).

Table 2. The number of leaves per plant (average by variant).

Options	03.05	10.05	17.05	24.05	31.05	07.06	22.06	29.06	05.07
Control	7.3	8.0	12.3	14.0	15.0	15.0	12.0	13.0	18.0
Ground 1:0.25	7.6	8.0	8.7	9.0	9.0	9.0	9.0	9.0	9.0
Ground 1:0.5	6.7	7.6	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Control + fertilization	7.0	8.0	12.0	14.0	15.6	16.3	13.7	20.7	20.7
Ground 1:0.25 + fertilization	7.6	8.0	8.7	9.0	12.0	13.5	16.0	16.0	20.0
Ground 1:0.5 + fertilization	6.7	7.6	9.0	9.0	10.0	12.0	13.5	15.2	19.2

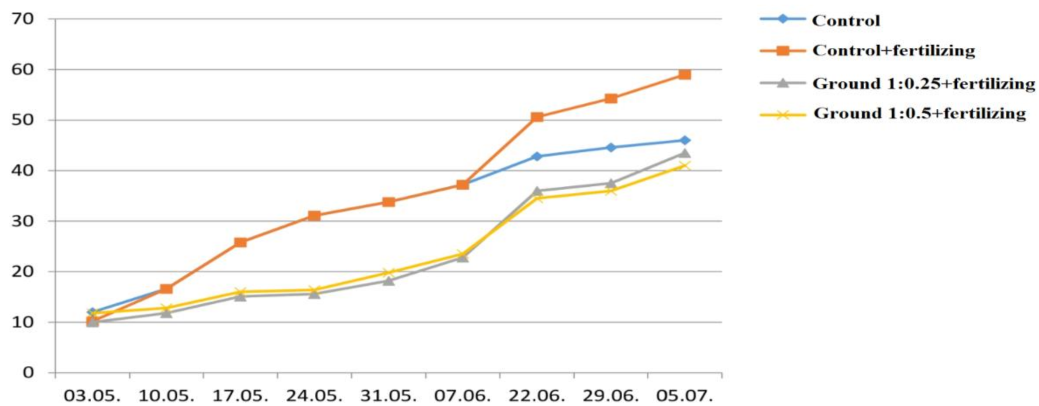

Figure 4. Plant height (cm) in the experimental plants.

For plant growth, the most favorable conditions developed resulted in the variant with traditional soil (Figure 4). *Sedum acre* L. noticeably showed an increased growth after fertilizing with full mineral fertilizer during watering on May 31. In the variants using municipal waste, the plant height was significantly lower than the control. Here, one can also note the responsiveness of amaranth plants to the application of NPK (Hasanova *et al*., 2021b).

Ascertaining the supply of nitrogen to plants can come from the data of a device that records the content of chlorophyll in leaves in arbitrary units. The maximum level, as marked at the control variants (200 and 205), variants with soil 1:0.5 + fertilization, and 1:0.25 + fertilization, showed a value of 3.7 to 3.3 times less (54 and 61). A decrease in plant growth and development in the variants with the addition of sewage sludge to peat compared to control variants could refer to the lack of nitrogen in the soil (Hasanova *et al*., 2021c).

All the processes in the life of plants occur in time and have a certain duration, beginning, and end. Moreover, if environmental conditions, including nutrition, correspond to the genotypes in each period of its development, then age-related variations appear synchronously with the development of the genotypes; it is practically difficult to separate from stage-specific and organoformative variations in ontogenesis (Akhundova *et al.*, 2025).

If specific environmental factors on some stages do not meet the conditions necessary for the plants' development, then the synchrony of these processes gets disrupted: the development and formation of plant organs slow down and eventually stop, and the aging process continues and can even accelerate due to developmental delay (Rayner, 2016; Hasanova and Abasova, 2024).

The time of the beginning of leaf color change and leaf fall was visible from the last week of July and the first 10 days of August, observed with a slight variation in date and

Species	**April**	**May**	**June**	**July**	**August**
S. acre L.					
	Flower bud swelling				
	Budding				
	Beginning of flowering - end of flowering				
	Fruit setting				
	Fruit ripening				

Figure 5a. Timing of phenological phases of the plant families.

Species	**May**	**June**	**July**	**August**
S. acre L.				
	Ripening			
	Budding			
	Pollination			
	Leaf fall			
	Beginning of flowering - end of flowering			

Figure 5b. Variations in the leaf coloration of the ornamental plant families.

some dependence on weather conditions. The beginning of stable frosts usually coincided with the end of leaf fall. The timings about the leaf color variations appear in Figure 5. Budburst/leafing out comprises a) recording the date when buds on trees and shrubs begin to open or when leaves start emerging and b) different plant species have specific triggers for budburst, often related to temperature and day length. Flowering includes a) noting when the plants produce flowers, b) observing the color, size, and number of flowers, and c) some plants flower in response to temperature, day length, and other environmental cues. Fruiting consists of a) documenting when the fruits start developing on plants, b) recording the size, color, and number of fruits, and c) the fruiting as influenced by factors, such as pollination and temperature (Bunyatova *et al*., 2025).

The phenological observations and morphometric parameters also revealed all the species have successfully passed through all stages of development (Figure 6). The sequence of seasonal variations in the same community has annual repeats; however, the timing of the phases and individual details were different (Hasanova and Asgarova, 2021). Phenological observations of the vegetative stages in *Sedum acre* L. (flower bud swelling, flowering, fruit setting, and fruit ripening) incurred studies for the first time and are seemingly innovative from an environmental viewpoint. Phenological observations of the seasonal development of taxa of the Crassulaceae family (on average for 2021–2024) and morphological indicators of plants during flowering phases showed that among ornamental plants, the most popular in the regions of the Absheron Peninsula and Azerbaijan is the *Sedum Acre* L. (Table 3a and b). The said species plays an effective role in phytoindication and has prospects for assessing the ecological state and landscaping of the urban environment.

CONCLUSIONS

The addition of sewage sludge and ash to the studied soil significantly altered the acidity to the alkaline side and also showed an enhanced ash content. All the elements necessary for plant life are present in coal ash, which is a type of rock of plant origin. The organic waste had a positive effect on the nutritional elements. The incorporation of sewage sludge remarkably increases the content of available phosphorus. Adding sewage sludge to peat positively affected plant growth. In soil, the increased proportion of waste did not increase the yield; however, such soil was advisable with NPK fertilization for growing *Sedum acre* L.

Figure 6. Using wastewater in the ornamental plants experiment.

Table 3a. Phenological observations of seasonal development of the family *Crassulaceae* taxa *Sedum acre* L. (average for 2021–2024).

Plant taxa	EA	FA	B	BF	MF	EF	BF	MRF
Sedum acre	17.04	10.06	04.07	20.08	29.08	25.09	30.09	07.11

Table 3b. Morphological parameters of plants at the flowering phase.

Plants	Stem length (cm)	Number of leaves	Leaf area (cm^2)	Stem length (cm)	Number of leaves	Leaf area (cm^2)
	2022	2023	2022	2023	2022	2023
Sedum acre	10.50 ± 0.74	11.20 ± 0.69	10.4 ± 0.89	10.6 ± 0.83	1.22 ± 0.16	1.21 ± 0.13

Note: EA = Early Appearance, FA = Full Appearance, B = Budding, BF = Beginning of Flowering, MF = Mass Flowering, EF = End of Flowering, BF = Beginning of Fruit Ripening, MRF = Mass Ripening of Fruits.

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