RESARCH ARTICLE

The effect of silicon-based preparation on the amount of humus and essential nutrients in the soil

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Abstract
In today's changing climate, increasing agricultural land use and soil productivity, as well as ensuring the availability of soil organic matter and soil essential nutrients, is becoming increasingly difficult. Farmers can increase crop yields by directly applying many commercial products and various pesticides to the soil, but this is only for this period. Due to the negative impact of such preparations on the basic properties of the soil, they can lead to the destruction of the soil structure in subsequent years. For long-term use of soil, it is very important that the fertilizers or preparations used are environmentally friendly and scientifically based. Today, to improve the relationship between soil and plant, many silicon-containing preparations are processed into the soil. This study examined the effect of silicon-containing Aminosid-Si and other Aminosid-Aton, Bionitrogen preparations on the amount of humus in the soil, the total content of N, P, K and N-NH_4, N-NH_3, P_2O_5 and K_2O has been studied. Studies have been conducted comparing the effects of silicon-containing preparations with the effects of other preparations. Because of the study, positive results were recorded for the preparation of Aminosid-Si.

Keywords: Soil; Silicon; Silicon fertilizer; Humus; gross and mobile nitrogen; phosphorus

Introduction

Soil is a non-renewable dynamic natural resource that is essential to life. As a substrate for growing plants, soil is important. In support of a wide range of animal and human activities. The soil is a supply of nutrients and water that is suitable for the needs of plants in their growth. Soil can also serve as a medium for decomposition and immobilization of materials added to the surface (in addition to the above-mentioned plant and animal debris), such as fertilizers and pesticides and wastes such as sewage sludge, animal waste and slurries, and composted waste (Urra et al. 2019) The soil is a multifaceted and ever-changing system where the interactions of biological, chemical, and physical elements lead to the conversion of materials. This process can potentially make harmful substances less hazardous while also immobilizing certain elements due to the interplay between added materials and the organic and inorganic components of the soil (Li et al. 2022). The breakdown of the potentially hazardous materials into less hazardous forms may be made possible by this immobilization (Tang et al. 2020).

These interactions and transformations may be long term, over decades, medium term over months or years, short term between individual events such as rainstorms, or almost instantaneous (Nemerow et al. 2009). Typically, the soil is composed of a series of vertical layers or horizons that are distinguished by differences in their physical, chemical, or biological properties (Adewara et al. 2024). Understanding the agrochemical properties of soil, or its nutritional components, is crucial when assessing the soil's nutritional value (Luo et al. 2023). Today, many studies are focusing on the presence of silicon in soil and its forms available to plants. Silicon (Si), next to oxygen, the most abundant element on the Earth's surface as well as in the soil, is useful for plants according to their growth and development in various environmental conditions. (Liang et al. 2005; Rasoolizadeh et al. 2018). Normally, Si is presented in various forms in the soil and in abundance especially the quartz, silicates, biogenic SiO_2 (e.g diatoms and phytoliths) and silica gel (Liang et al. 2005; Sommer et al. 2006). The extractable forms of Si in the soil include amorphous, active, and water soluble Si (Khan et al. 2021). Water-soluble forms of Si can be directly available to plants, while the remaining Si is first converted to a water-soluble form under favorable conditions and then readily available to plants. (Ali et al. 2020). Si as silicic acid ranges from 0.1 to 0.6 mM in the soil, which is roughly two times higher than the concentration of phosphorus in the soil solution (Epstein 1999). It has been reported that Si is not on the list of essential elements, but it is involved in growth and development processes and has extensive functions in plant metabolism, especially in graminaceous and cyperaceae species (Epstein 1999; Liang et al. 2005). Nevertheless, numerous environmental and soil factors have a substantial impact on the bioavailability of Si in the soil and its subsequent transportation to plants (Hao et al. 2020). The occurrence of abundant rainfall causes the leaching of silicon (Si) and the subsequent decrease in soil pH, which in turn adversely affects the biological silicon pools present in the soil. Consequently, this leads to a reduction in the availability of bioactive silicon for plants (Schaller et al. 2021). Additionally, poor soil management techniques and excessive crop harvesting rates negatively affect the silicon concentration in the soil solution, resulting in heightened stress levels in plants (Puppe 2020; Schaller et al. 2021). The positive roles of Si vary with different types of biotic and abiotic stresses (Epstein 1999). According to (Epstein 1999; Sommer et al. 2006) modified definition, an element is deemed essential if it satisfies either one or both of the following criteria: (i) the element plays an active role in the formation of molecular structures involved in metabolic processes in plants, and (ii) the absence of the element in a plant leads to abnormalities in growth and development when compared to plants with lower deficits. Consequently, it can be anticipated that Si will be recognized as an essential element for higher plants in the near future. (Pavlovic et al. 2021).

The monomeric or monosilicic (H_4SiO_4) nature of silicon in the soil solution allows for easy absorption by the root system and subsequent translocation to the aboveground parts of plants, leading to accumulation (Imtiaz et al. 2016). The soil characteristics can be modified by enhancing air and water regimes, improving nutrient contents such as nitrogen, phosphorus, and potassium, raising soil pH, mitigating the toxicity of heavy metals by enhancing soil physical and chemical properties, and facilitating the formation of new silicate complexes (Matichenkov & Bocharnikova 2001). The absorption of Si by the plant root system enhances the plant's well-being by diminishing the uptake and movement of heavy metals from the roots to the shoots. Additionally, it activates the antioxidant system, facilitates chelation, compartmentalization, and regulates the gene expression of heavy metal transporters. (Hou et al. 2023). Similarly, Si plays a role in mitigating heavy metals toxicity, stimulating soil phosphorus (P) activity, and enhancing the uptake of P by plant roots alongside other necessary nutrients. (Kim et al. 2014). Furthermore, the health of soils is closely linked to soil physical and chemical properties, soil ecological functions, and soil fertility, all of which are influenced by soil bacterial communities (Kleytsova et al. 2022). Incorporating silicon or silicon-based fertilizers into the soil can bring about alterations in the bacterial community structure and the physicochemical properties of the soil. These modifications may influence the restriction, immobilization, and transformation of pollutants like cadmium (Ma et al. 2011). Soil salinity is a significant constraint that hinders plant growth and decreases yield in arid and semi-arid regions. Nevertheless, the adverse effects of salt stress can be alleviated through the use of silicon (Zhu et al. 2004). Previous studies have shown the beneficial impact of silicon on various plant species, including cucumber, wheat, tomato, rice, barley, and maize, when cultivated in saline conditions (Zhu et al. 2004)

Silicon effectively enhances plant growth characteristics and biomass by enhancing the physicochemical properties of the soil in relation to soil nutrients and minerals (Korndörfer & Lepsch 2001). Upon Si addition, a significant reduction in the soil available N and P which directly reflects more uptake of N and P by plants due to Si application (Campos & Da Silva 2023). In addition, the presence of P competing with Si for adsorption sites on clay particles results in the release of P, which becomes easily available to plants. Plants can then absorb this nutrient through physio-chemical mechanisms, facilitated by the large surface area of mineral Si. (Owino-Gerroh & Gascho 2005). The large proportion of chemically adsorbed P was converted to insoluble phosphates with Al-P, Ca_8-P, Ca_{10}-P and Fe-P that reduced its bioavailability in the soil (Owino-Gerroh & Gascho 2005; Wang et al. 2010). However, Si at higher doses also increased the soil pH by reducing soil K availability and provided favorable environment for better growth of pakchoi (Wang et al. 2020) reported lower amount/values of soil organic matter and electrical conductivity in the presence of higher Si concentration and a significant correlation between soil properties and growth of plants. Literature has demonstrated that the concentration of silicon in soil plays a crucial role in improving soil nutrients and physicochemical properties necessary for the growth of plant roots and shoots, especially in the presence of heavy metal toxicity (Zhu et al. 2019). In the same context, the presence of a small amount of other elements like calcium, iron, magnesium, and manganese, in addition to silicon as mineral-Si, also contributed to the improvement of soil quality and facilitated plant growth (Ning et al. 2014). Moreover, the influence of silicon on the availability of soil mineral nutrients is not uniform, as various plant species possess varying abilities to accumulate silicon and other minerals that are associated with silicon aggregation (Greger et al. 2018). Hence, elucidating the comprehensive function of Si in various plant species remains challenging due to the abundance of studies conducted on Si accumulating plants rather than others (Deshmukh et al. 2017). A variety of silicate containing materials that can be used as Si fertilizers. The naturally occurring Si containing materials are wollastonite (21–25% Si; $CaSiO_3$), olivine (ca. 20% Si; $MgSiO_3$), diatomaceous earth (38–42% Si) that can be extracted from earth's surface and used as fertilizers (Haynes 2019). Furthermore, most of the Si fertilizers are by-products of various industrial materials Application of slags and wollastonite led to a notable increase in soil pH and soluble Si concentrations. This enhancement can be attributed to a strong interplay between soluble Si and soil pH levels. Although no strong correlation was observed between Si adsorption to soil particles at low pH values (5−6), an increase in pH facilitates Si adsorption to soil colloids, consequently boosting the availability of soluble Si. (Haynes 2014).

Since humus forms take into account biological, biochemical, and chemical factors, they are good indicators of soil functionality. Since the inception of soil science, the significance of humus forms and the necessity of humus form classifications have been acknowledged (Andreetta et al. 2011). Humus is an essential component of soil, resulting from the breakdown of plant and animal materials by microorganisms. It exists in various shades, from brown to black, and contains around 60 percent carbon, 6 percent nitrogen, as well as lesser amounts of phosphorus and sulfur. (Porte 2021) The surrounding vegetation determines the quantity and quality of organic matter that accumulates in the humipedon, and soil micro-, meso-, and macrofauna (Semeraro et al. 2023) as well as climate conditions (Zanella et al. 2018) influence how this organic matter decomposes, forming a unique layer sequence known as the humus form. (Jabiol et al. 2013). Humus forms can serve as an initial indicator of the soil's ability to act as a carbon sink because of their variability, which is a reflection of the differing rates at which organic matter degrades in various environments (Loranger et al. 2003). Soil organic matter and its transformation into small molecules must be ongoing. Today, global climate change and drought conditions have a negative impact on the stability of biological processes in soils. As a result, land use and economic efficiency decrease. Therefore, it is very necessary to use products that are effective in improving the biological processes of the soil and maintaining the amount of nutrients in the soil.

Material and Methods

Experimental design and location

Research work was carried out in the field of Avez, Mirshod, Rustam F/H in the Bukhara region. The goal was to study how to influence the drugs of Aminosid-Aton, Aminosid-Silicon and Bionitrogen on humus and general and mobile nitrogen, phosphorus and potassium in conditions of stress and drought. The soil was cultivated in two rounds with these preparations. The first, cotton seeds processed with preparations for 24 hours, and then planted in the soil. Secondly, the suspension of preparations was sprayed on the soil in June. The options were allocated 0.0025 km 2 and 9 kg of seeds were planted. 100 g of the preparations were diluted by 5 liters.
Soil Sampling: The soil samples were collected at three depths: the 0-30, 30-70, 70-100 cm. Soil samples were processed in the laboratory by removing visible plant residues and stones larger than 2 mm immediately after sampling. Soil samplings were then air-dried.
Soil sample analyses: The air-dried soil samples were ground to pass through a 2 mm sieve for laboratory analysis. Soil samples were digested in a tri-acid mixture (HNO_3, $HClO_4$, and H_2SO_4 at a 3:1:1 ratio) for determining total phosphorus (Total P). The P concentration in the digest was determined colorimetrically using the vanadomolybdate method. Soil organic phosphorus (P) was determined by combustion at 5500C and extraction with 4 M H_2SO_4. The Michigan method was used to determine available P using the colorimetric method after the extraction with 1% $(NH_4)2CO_3$ (GOST 26205-9 2021). Soil inorganic P fraction: Inorganic P (P) fractions were measured according to a fractionation scheme of Ginzburg and Lebedeva (1971) and Ginzburg (1981) (Ginzburg, K.E., Lebedeva, L 1971). The amount of humus in the soil was determined by the method of I.V. Tyurin, taken from the 0-30, 30-70, 70-100 cm layers of the soil. Calculations of humus in the soil in tons were calculated based on the weight (mg) of the 0 - 30 cm layer of 1 cm cube of the specified area volume unit (Meylikovich et al. 2022).

Composition of preparations

Aminosid Aton-sodium ortho-nitrophenolate 2%, sodium para-nitrophenolate 2%, naphthylacetic acid 2%, Zinc (Zn) 0.5%, boron (B) 0.5%, Sulfur (S) 0.5%, molybdenum (Mo) 0.5%.;
Aminosid Silicon- silicon (Si) 17%, nitrogen (N) 9%, macro- and microelements; *Bionitrogen*-the basis of the biological product Bionitrogen" is the nitrogen-assimilating bacterium *Azotobacter chroococcum* and its natural compounds useful for plants - polysaccharides, vitamins, amino acids. The bacterium multiplies in the roots of plants and absorbs nitrogen from the air.

Processing of the obtained results. The obtained results were processed using GraphPad Prism 8.0.1(244) software. The arithmetic mean (M), standard deviation (±m) and statistical significance (P) were examined. Results less than $P<0.05$ were considered statistically significant.

Statistical Analysis

Analysis of variance (ANOVA) was performed to assess the differences in soil nutrients (humus, nitrogen, phosphorus, and potassium) across various treatments and soil depths using Microsoft Excel 2021. The collected data were first checked for normal distribution, and after satisfying the assumptions, data were analyzed using a completely randomized design (CRD). For multiple comparison tests among the treatments, the least significant difference (LSD) test at $p < 0.05$ was applied to determine significant differences between the means.

Results

Humus is classified into mor, mull, or moder formations according to the degree of its incorporation into the mineral soil, the types of organisms involved in its decomposition, and the vegetation from which it is derived. In terms of the amount of humus, the level of humus supply in the arable soil horizons of the study area is low. It can be seen (Figure. 1) that in the 0-30 cm layer in the control variant, 0.85% is observed, and in the experimental variants (processed with Aminosid-Aton and Bionitrogen in the soil) a slight increase is observed and approximately the same result, approximately 0.976 and 0.998% respectively.

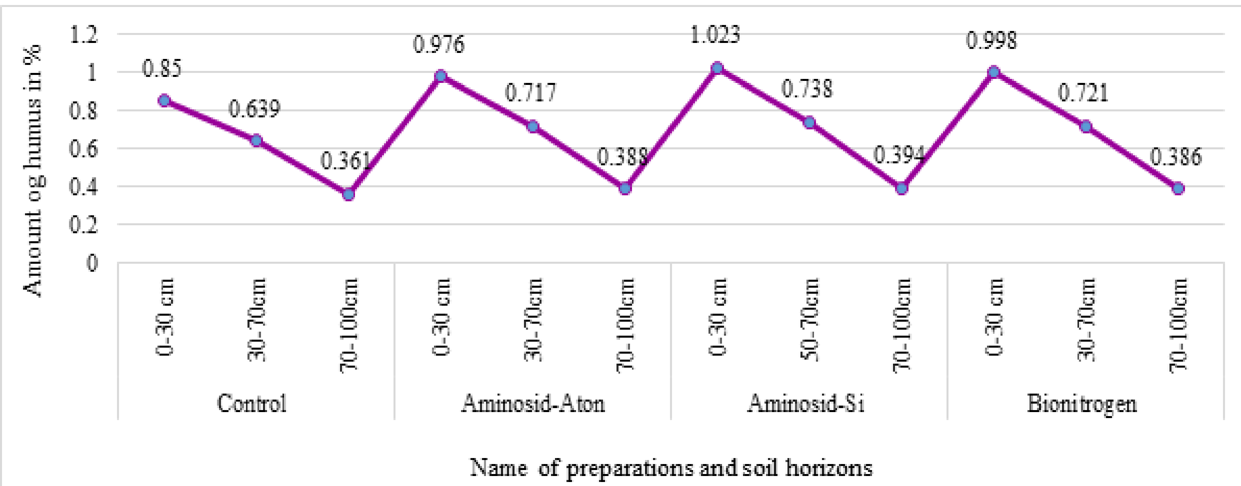


Figure. 1 (The influence of preparations on the humus content of soils in the study area)

The Aminosid-Si preparation showed a higher number of 1.023 compared to the control. This showed that the amount of humus in this preparation increased by 0.172% compared to the control. It has been established that the silicon contained in the preparation is of great importance for changing the biological activity of the soil under conditions of arid climate and low salinity. It can be said that the results are consistent with the literature (Kar 2021). Research work continues to study the total amount of nitrogen, phosphorus and potassium in the soil. The results are presented in Fig. 2.

As can be seen from the table, the level of total K, P and N_2 in the region is also in the low supply area. Soil treatment with the preparations was assessed by comparing the total content of K, P and N_2 with the control. In the control, the total amount of N in the 0-30 cm soil horizon was 0.071%. Despite this, it was found that the Aminosid Aton and Bionitrogen experiment variants increased compared to the control by 0.015% and 0.016%, respectively. Aminosid-Si had a significant effect on the amount of total N_2, increasing by 0.02% compared to the control. Towards the lower soil layer, the total amount of K, P and N_2 decreased.

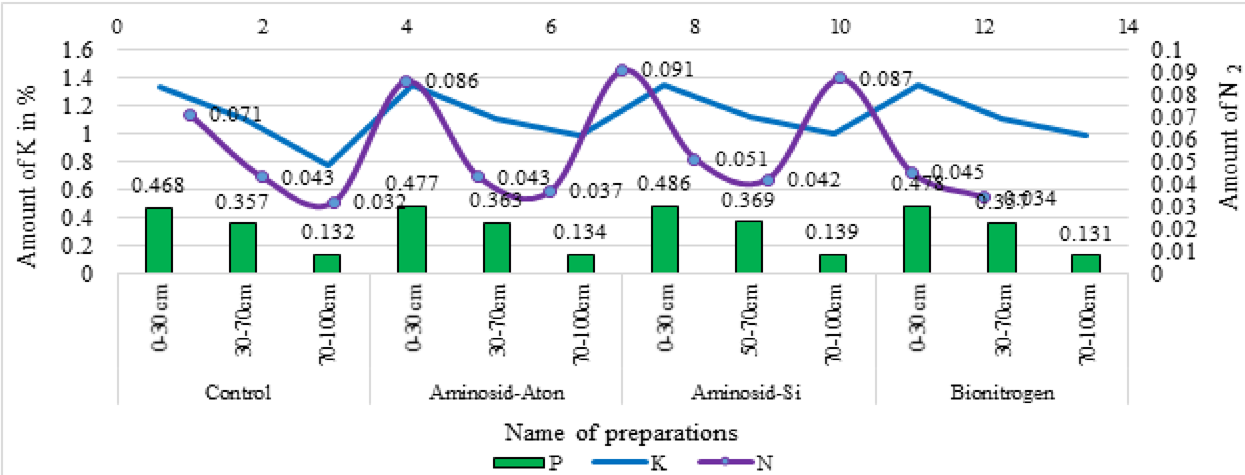
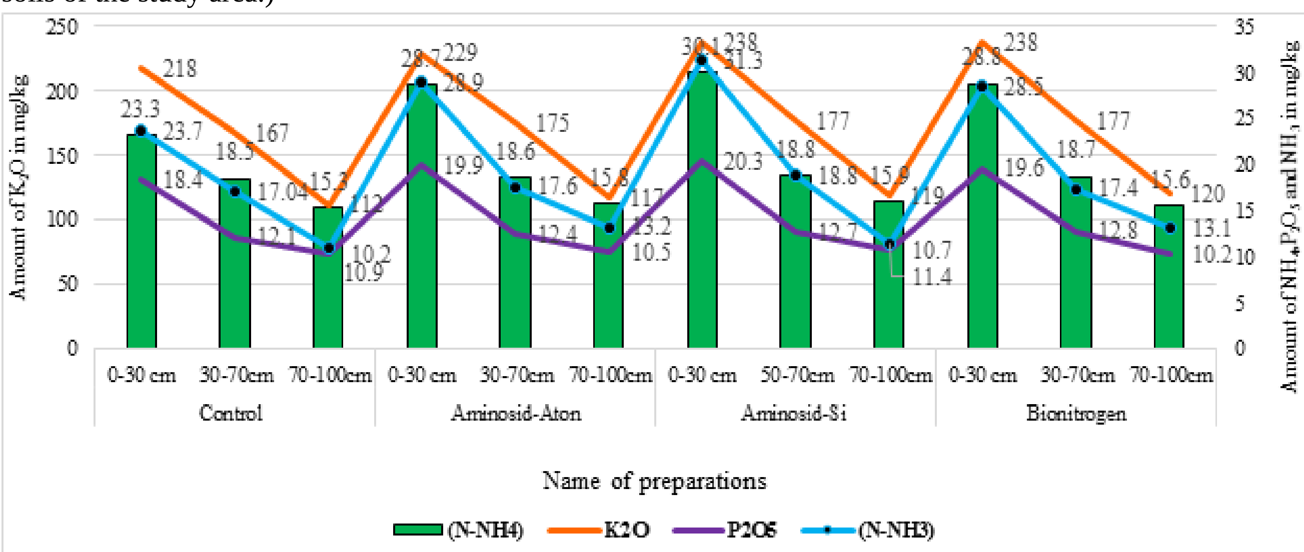


Figure. 2 (The influence of preparations on the content of gross nitrogen, phosphorus and potassium in soils of the study area.)

Small differences in the increase in Aminosid Aton, Bionitrogen and Aminosid-Si compared to the control were shown for 0.005, 0.002 and 0.01, respectively. This research work continues to study the effect of the preparation on the mobile forms of K, P and N_2. The results are presented in Fig. 3.

Figure. 3 (The influence of preparations on the content of mobile nitrogen, phosphorus and potassium in soils of the study area.)



It is known that sufficient amounts of nitrogen, phosphorus and potassium, assimilated by plants in the soil, ensure high productivity and, as a consequence, economic efficiency. Therefore, the soil must have a sufficient amount of (N-NH_4), (N-NH_3), P_2O_5, K_2O. The soils of the study area are also poor in mobile forms of N-NH_4, N-NH_3, P_2O_5, and K_2O. Today the climate is changing, so it is very important to use necessary and environmentally friendly soil preparations. It was noted that when using preparations, the amount of NH_4, N-NH_3, P_2O_5, and K_2O in mobile form increases. Thus, in the 0-30 cm soil horizon, the amount of N-NH_4 (mg/kg) increased by 5,4, 6,8, 5,5 mg/kg, respectively, in Aminosid-Aton, Aminosid-Si and Bionitrogen compared to the control. Additionally, it can be said that the amount of N-NH_3 in the soil in the control variant is 23.7 mg/kg and is considered low in terms of the level of N-NH_3 supply in the soils of the study area. After treating the soil with Aminoside-Si, a transition to a moderately provided level occurred. In this case, it is advisable to evaluate the composition of the preparations by the presence of Si (17%) and N_2 (9%), as well as macro- and microelements. There is also increasing information in the literature about the significant role of silicon in soil under drought and salinity conditions (Matichenkov & Bocharnikova 2001; Pallavi & Prakash 2019). The amount of mobile P_2O5 and K_2O was higher in Aminosid-Si compared to other preparations. Compared to the control, higher values were obtained with an increase of 1.9 and 20 mg/kg, respectively.

Discussion

According to the results of studies conducted on irrigated meadow-alluvial soils, the amount of humus in the arable soil layer of the Kunji-Kala massif varies from 1.59% to 0.540%. In the lower layers, its indicators decrease horizontally. It ranges from (0.630% to 0.100%) in percentage terms. The upper limit of humus reserves was 62.56 t/g in the 0-30 cm horizon and in its lower layers the results were about 6.216 t/g. According to the FAO classification, in experiments conducted over 3 years, in the soils of the experimental area there was a shift from the lower part to the upper limit of the low humus content. Because increasing the amount of humus in the soil is a labor-intensive process of humification (Humification refers to the breakdown of organic materials in soils and composts leading to the formation of humus). But in addition to the initial organic products that fall into the soil, there are also intermediate components (with carbon, nitrogen, a small amount of sulfur and phosphorus) that continue to decompose (Abakumov et al. 2018; Adewara et al. 2024). It is the participation of groups of enzymes and certain types of microorganisms that catalyze the process of decomposition of these products. It is known from the literature that the preparations used above have a positive effect on the activity of biological processes in the soil.

In recent years, positive results have been increasing in all types of soil research with silicon fertilizers (Bocharnikova et al. 2010; Kovács et al. 2022; Dong et al. 2024).

Silicon can promote the decomposition of organic compounds by increasing microbial populations in the soil. For example, bacteria associated with the metabolic functioning of nitrogen and carbon in soil, such as Anaerolineae (Yan et al., 2018), Flavobacteriales (Bowman and Nichols, 2005), Nitrospirae (Xu et al., 2016), Bacillales (Logan and De Vos, 2011) were found in excess in soils enriched with silicon and heavy metals. During the implementation of this scientific work, it was found that silicon preparations actually stimulate nutrients in the soil, and it is clear that this is consistent with the results of the literature (Reithmaier et al. 2017; Schaller et al. 2019). Aminosid-Aton, Aminosid-Si, and Bionitrogen preparations, which are considered as research subjects, received positive results compared to the control. In particular, the Aminosid-Si preparation, which contains Si (17%), received relatively positive results. The stimulation of soil C: N: P amounts by Si processed to the soil environment was also analyzed by comparison with literature results (Jianfeng & Takahashi 1991).

Conclusion

In this work, experiments on the application of Si fertilizers to the soil were studied and the amount of humus, the amount of N2, K, P, as well as their mobile forms over the past three years were determined. The results show that research interest in studying the effects of silicon-based fertilizers on soil properties has increased rapidly in recent years. The scientific interest in conducting field experiments is to test how soil organic components and essential plant nutrients increase with the addition of fertilizers. Si, which shows the natural motivation of researchers to achieve full utilization of this fertilizer and make it applicable to farmers. Considering that all experimental work on the application of silicon fertilizers to the soil has only a positive effect, it is necessary to provide a scientific explanation to farmers for the use of these fertilizers in arid climates, abiotic and biotic conditions. The application of these fertilizers to the soil in the conditions of Uzbekistan has shown truly significant results. Although this could not provide a high increase in the humus content and the number of mobile forms of N_2, P, K, nevertheless, a slight increase in their content was observed and their content remained longer in the soil. Consequently, application of these Si fertilizers to the soil over many years can lead to optimization of agrochemical and biological processes in the soil, which creates prospects for large-scale use of agricultural land and provides economic benefits.

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