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Comparison of The Effectiveness of Struvite and Some Commercial Fertilizers on The Growth of Lettuce

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ABSTRACT

This paper aimed to examine the effectiveness of struvites obtained from NH_4 recovery from biogas liquid fermented products as fertilizers. For this, the effectiveness of two type of struvite (STR1 and STR2) on lettuce grown in acid and calcareous soils was compared with widely used commercial fertilizers, namely diammonium phosphate (DAP), monoammonium phosphate (MAP), triple superphosphate (TSP), and 20-20-20. Therefore, 200 $mgkg^{-1}$ phosphorus equivalent amount of each material was mixed with the soil. The study was performed as a pot experiment under greenhouse conditions. The experiment was arranged with three replications according to a completely randomized design, and each soil was evaluated individually. The results indicated that the treatments significantly affected the growth parameters and leaf SPAD values for each soil. In both soils, the highest plant fresh weight values obtained from STR1 and STR2 applications despite being in the same statistical group as DAP and 20-20-20 fertilizers in terms of their effectiveness. At the same time, it was observed that struvite applications in soils were either more effective or comparable to other chemical fertilizers in terms of other parameters. Overall, it can be concluded that both struvites are superior or comparable to other chemical fertilizers in the examined parameters.

Keywords: Chemical fertilizers, fertilizer efficiency, lettuce, struvite, yield parameters

Struvit ve Bazı Ticari Gübrelerin Marulun Büyümesi Üzerindeki Etkinliklerinin Karşılaştırılması

ÖZ

Bu makale, biyogaz sıvı fermente ürünlerinden NH_4 geri kazanımından elde edilen struvitlerin gübre etkinliğini incelemek amacıyla yürütülmüştür. Bunun için iki struvitin (STR1 ve STR2) asit ve alkali topraklarda yetişen marul bitkisi üzerine olan etkinliği, yaygın olarak kullanılan ticari gübreler diamonyum fosfat (DAP), monoamonyum fosfat (MAP), triplesüperfosfat (TSP) ve 20-20-20 gübresiyle karşılaştırılmıştır. Bu nedenle, her bir materyalden 200 $mgkg^{-1}$ fosfora eşdeğer miktarda tartımlar yapılmış ve toprakla karıştırılmıştır. Deneme sera koşullarında saksı denemesi şeklinde yürütülmüştür. Deneme tesadüf parselleri deneme desenine göre üç tekerrürlü olarak düzenlenmiş ve her toprak ayrı ayrı değerlendirilmiştir. Her bir topraktan elde edilen sonuçlar, incelenen büyüme parametrelerinin ve yaprak SPAD değerlerinin uygulamalardan anlamlı ölçüde etkilendiğini göstermiştir. Her iki toprakta da etkinlik açısından DAP ve 20-20-20 gübreleri ile aynı istatistiksel grupta yer almalarına rağmen en yüksek bitki yaş ağırlık değerleri STR1 ve STR2 uygulamalarında elde edilmiştir. Aynı zamanda her iki toprakta da sutrivite uygulamalarının diğer parametreler açısından ya daha etkili olduğu ya da diğer kimyevi gübrelere göre kıyaslanabilir düzeyde olduğu gözlenmiştir. Genel değerlendirme yapıldığında, her iki struvitin de incelenen parametrelerde diğer kimyasal gübrelere göre üstün veya karşılaştırılabilir olduğu söylenebilir.

Anahtar Kelimeler: Kimyasal gübreler, gübre etkinliği, marul, struvit, verim parametreleri

INTRODUCTION

As the population continues to increase rapidly day by day, attempts to meet its needs for food and other agricultural products are becoming more important. Agricultural lands are the main area of crop production. However, agricultural areas are gradually decreasing due to many reasons. Additionally, the fertility of agricultural soils is decreasing due to various factors. In this case, it is necessary to maximize yield from each unit of agricultural areas. One of the most successful approaches for increasing the soil fertility is through the use of fertilization. Chemical fertilizers are highly

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effective in making the soils fertile, as they rapidly dissolve and have immediate effects on plant growth. However, their misuse can cause serious problems. The production of chemical fertilizers requires non-renewable energy and using natural resources, which not only leads to a rapid consumption of natural resources, but it also causes to numerous environmental problems.

Due to the excessive consumption of natural resources and possible environmental problems, environmentally friendly resources should be used as an alternative to chemical fertilizers. Struvite is one of the alternative sources that can be utilized for this purpose [1, 2, 3]. Struvite is a recovered crystalline chemical obtained from different types of sources such as wastewater. Struvite precipitation is mainly used to reduce the phosphorus and ammonium concentration in wastewaters that arise from different types of sources. The chemical formula of struvite is $NH_4MgPO_4.6H_2O$ and it contains 12.5% P, 5.7% N, and 9.9% Mg on a theoretical basis [4]. The theoretical fertilizer value of struvite varies depending on the source and recovery process [5, 6, 7]. Struvite is slightly soluble in water and soil solutions, slow-release struvite has been found to be a highly effective source of phosphorus, nitrogen and magnesium for plants through both foliar and soil application [7, 8]. Numerous studies have shown that struvite is superior or comparable to most of the conventional P fertilizers on different plants [9, 10, 11]. It has been reported that struvites can compete with chemical fertilizers in various studies because they contain a significant amount of nutrients. In a study conducted by Uysal et al. [12], it was found that struvite precipitate obtained from yeast industry significantly affected fresh and dry weights, as well as nutrients and elements uptakes in tomato plants. The application of struvite to the soil in barley cultivation increased the soil P concentration, and at the same time, plant yield increased with increasing P and Mg uptake [13].

The aim of this study was to investigate the fertilizer efficiency of two struvite types in greenhouse lettuce cultivation and to compare the effects of struvite types and some chemical fertilizers in terms of their effects on plant growth and leaf SPAD value.

MATERIALS AND METHODS

Struvites and Chemical Fertilizers

In this study, two types of struvites (STR1 and STR2) were used. The struvites were obtained from a liquid fermented product produced at Süleyman Demirel University, Engineering and Architecture Faculty, Environmental Engineering Department by Huseyin Yazıcı. The powdered form of the struvites is given in Figure 1.

The fertilizer effectiveness of struvites was determined by comparing them with widely used commercial fertilizers, namely diammonium phosphate (DAP), monoammonium phosphate (MAP), triple superphosphate (TSP), and 20-20-20 fertilizer. The elemental compositions of struvites and each commercial fertilizer are given in Table 1.

Figure 1. Powdered form of struvites recovered from liquid fermented product

Table 1. Elemental composition of struvites and commercial fertilizers used for the experiment

Total Nutrient Contents	STR1	STR2	DAP	MAP	TSP	20-20-20
Total P (%)	7.25	9.85	20.0	26.6	18.3	8.7
Total N (%)	2.61	2.77	18	12	-	20
Total K (%)	4.16	4.39	-	-	-	16.5
Total Ca (%)	0.88	0.82				
Total Mg (%)	2.92	2.64				
Total Zn ($mg.kg^{-1}$)	186	117				
Total Fe ($mg.kg^{-1}$)	536	755				
Total Mn ($mg.kg^{-1}$)	72	67				
Total Cu ($mg.kg^{-1}$)	7	11				

Experimental Soils

Acidic soil was brought from Rize, located in the Black Sea region of Turkiye, while the calcareous soil was taken from the agricultural research area of Isparta University of Applied Sciences. After the collection, the soils were dried for approximately 1 week until they reached an air-dry state, then sieved through a 1 cm sieve prior to filling them in each pot. Some important characteristics of the soils are provided in Table 2.

The study was performed as a pot experiment in greenhouse conditions over a two-month period and 2 kg of soil was used for each pot. Prior the planting, all the fertilizers and struvites were applied in powdered form to the soils at 200 $mg.kg^{-1}$ P, and then mixed by hand. No other fertilization was done. In addition, a set of 3 pots was used as a control group in which no fertilizer was applied. Afterwards, seedlings were planted. One lettuce seedling was planted in each pot and left to grow for 2 months. The plants were watered with tap water at 70% of water holding capacity, and irrigation intervals were adjusted according to the plants demand. The experiment was arranged according to a completely randomized design with three replications. Each soil was evaluated individually.

Table 2. Some important characteristics of the soils used for the experiment

Properties	Acid Soil	Calcareous Soil
Organic Matter (%)	3.2	1.4
pH (1/2.5 Soil-Water)	5.5	7.8
EC ($dS\ m^{-1}$, 1/2.5 Soil-Water)	0.2	0.2
$CaCO_3$ (%)	1.6	27
Texture	Clay Loam	Silty Loam
P ($mg.kg^{-1}$)	7.1	6.7
K ($mg.kg^{-1}$)	217	677
Ca ($mg.kg^{-1}$)	3700	5600
Mg ($mg.kg^{-1}$)	617	989
Fe ($mg.kg^{-1}$)	7.6	3.1
Zn ($mg.kg^{-1}$)	0.5	0.84
Mn ($mg.kg^{-1}$)	6.5	2.8
Cu ($mg.kg^{-1}$)	1.8	3.8

Plant Measurements

After a two-month growth period, the plants were harvested along with their roots. Before harvest, the soils were saturated with water to minimize root loss. The roots were cleaned from the soil by being washed with water, then were placed on the filter paper to minimize excess water (Figure 2-a). Head height and width of lettuce heads were measured by a ruler (Figure 2-b). The root collar diameter was measured at the junction point of root and head using a manual caliper (Figure 2-c). The length of the roots was determined using a ruler (Figure 2-d). Once the head and roots were separated, their weights were measured by digital scales.

Analytical Procedures

For struvite analysis, 1 g of sample was wet digested in a mixture of nitric and perchloric acid then analyzed for total P, K, Ca, Mg, Fe, Cu, Zn and Mn using an atomic absorption spectrophotometer. Nitrogen concentration was determined according to the Kjeldahl method, as described for chemical fertilizer analysis in [14]. For the soil analysis, air-dried soils were sieved through a 4 mm sieve. The pH and EC of the soils were measured in a soil/water suspension using a combined pH-EC meter. The texture, $CaCO_3$ and organic matter were measured using the methods described by Bouyoucos [15], Allison and Moodie [16] and Walkley and Black [17] methods, respectively. Available P concentration in calcareous soil was determined according to Olsen [18], while in acid soil according to Bray and Kurtz [19]. Exchangeable cations (K, Ca, Mg) and DPTA-extractable microelements (Fe, Zn, Mn, and Cu) were determined as described by Jackson [20] and Lindsay and Norvell [21].

Figure 2. Plant measurements

SPAD Measurement

Leaf green color intensity was measured on four different leaves of each plant (four readings for each lettuce plant) after harvest from the mid-top leaf region with a SPAD 502 chlorophyll meter (Konica Minolta, Japan). The mean of four readings was accepted as one value of leaf green color intensity.

RESULTS

Head Weight, Height and Width

The effects of struvites and chemical fertilizers on the fresh weights, height and width of lettuce heads can be seen in Figure 3, Figure 4, and Figure 5, respectively. As shown in the figures, the treatments significantly affected these parameters ($P<0.01$). In acid soil, the most effective applications on the head fresh weights were STR1 (133 $g.plant^{-1}$), STR2 (129 $g.plant^{-1}$), and 20-20-20 fertilizer (125 $g.plant^{-1}$). The lowest head weights were observed in the plants grown under control (46.7 $g.plant^{-1}$) and TSP (46 $g.plant^{-1}$) treated pots. Similar to the acidic soil, control and TSP were the least effective applications on the head fresh weight of the lettuce grown under calcareous condition. The head width of the plant grown in acid soil varied between 14.30-23.20 cm, and the head height was between 10.7-17.3 cm. In calcareous soil, these changes were between 15.8-26 cm for head width and 14-18.2 cm for head height. Control group and TSP applications were found to be the most ineffective applications in both soils. It was observed that STR1, STR2, 20-20-20, and DAP fertilizers were the most effective applications for increasing the head width and height of plants grown in acid soil, followed by MAP fertilizer. In calcareous soil, the most effective applications on head width were STR1 and STR2. It was determined that STR2, STR1, 20-20-20, and DAP had similarly higher effects on head height values. Control group and TSP showed the lowest effect on lettuce height in calcareous soil as in acid soil. The overall effects of all treatments on lettuce growth can be seen in Figure 6.

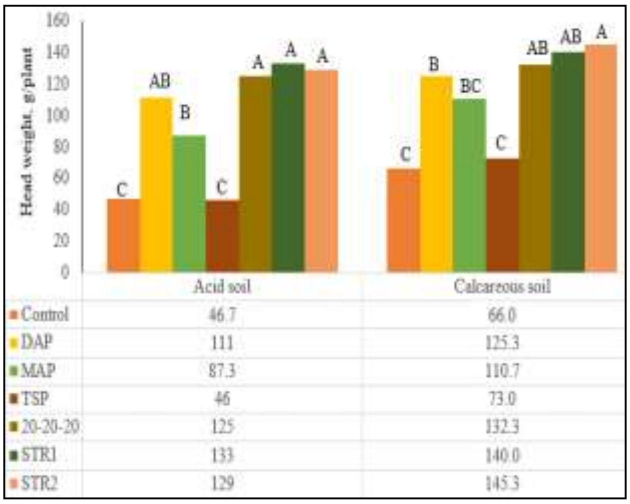

Figure 3. Effect of treatments on head fresh weight of lettuce

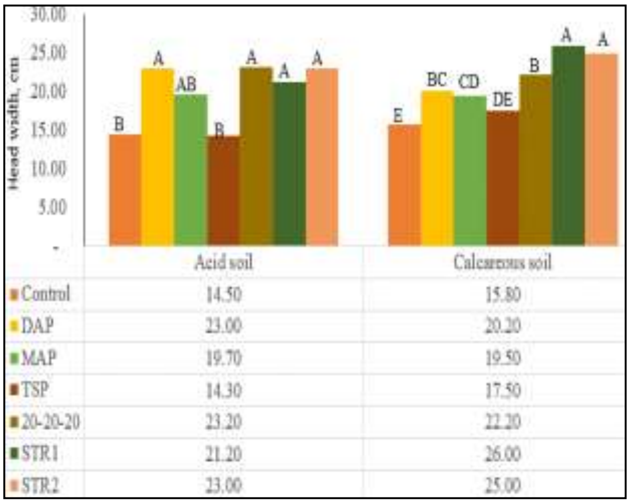

Figure 4. Effect of treatments on the head width of lettuce

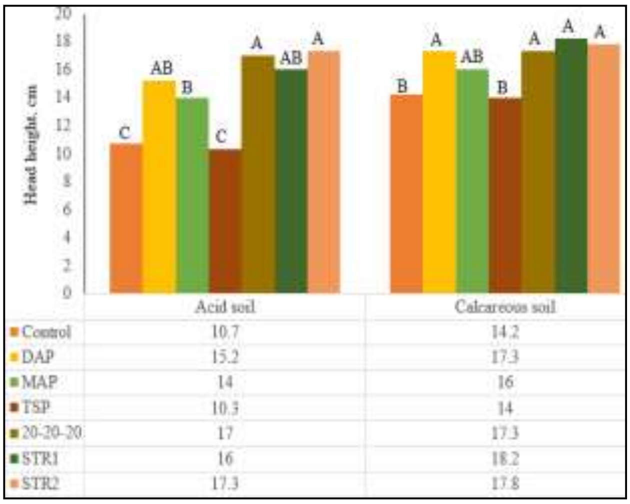

Figure 5. Effect of treatments on the head height of lettuce

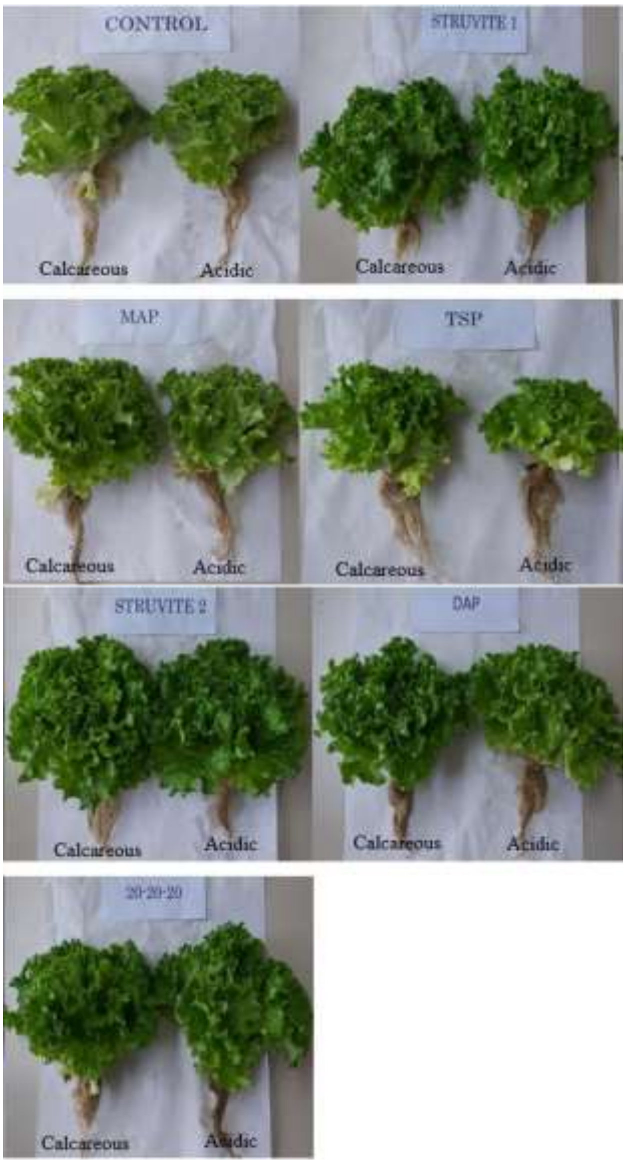

Figure 6. Effects of the treatments on lettuce growth

Root Weight, Root Length and Root Collar Diameter

The different applications had a significant effect on root weight and root length in acid and calcareous soils (P<0.01). Root weight per plant ranged between 7.4 and 12.2 g under acid soil conditions (Figure 7). In acidic soil STR1 had the most significant effect on root fresh weight, the control group had the least. Similarly, in calcareous soil, control group plants had the lowest weight at 5.9 g per plant. Under calcareous conditions, control group was the least effective in promoting root weight, followed by both struvites. MAP fertilizer showed the highest effectiveness in calcareous soil with a fresh root weight of 11.8 g per plant. However, MAP took place at the partially in same statistical group with DAP, TSP, 20-20-20, and STR1. STR2 ranked below all these fertilizers in terms of its effect on root development (Figure 7).

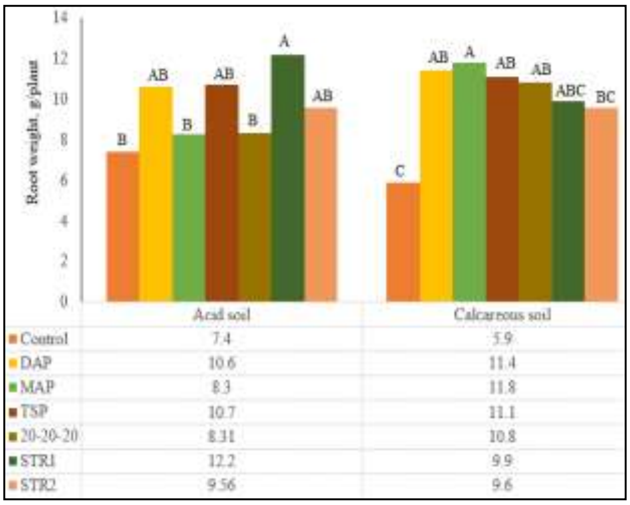

Figure 7. Effect of treatments on root fresh weight

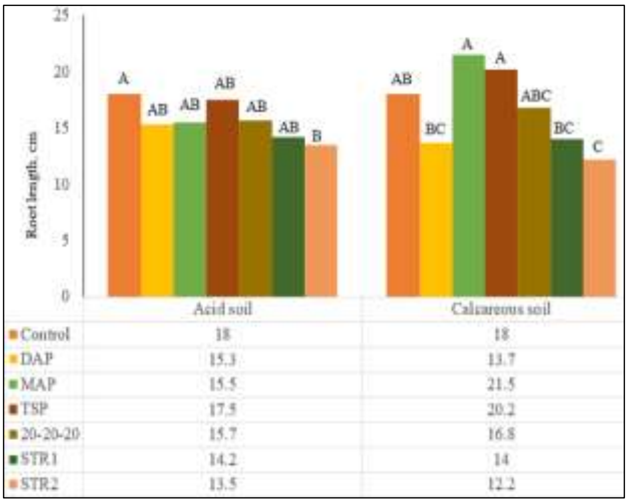

Figure 8. Effect of treatments on root length

Regarding root length, it was seen that the length of roots varied between 13.5 cm (STR1) and 18 cm (control) in acid soil, and between 12.2 cm (STR2) and 21.5 cm (MAP) in calcareous soils (Figure 8). As indicated here, control treatment on acidic soils and MAP and TSP treatments on calcareous soils had the longest root lengths compared to other treatments. The treatments had a significant effect (P<0.01) on root collar diameters in both types of soil (Figure 9). The variations in root collar diameters of the plants grown in acid soil were between 1.05 cm (control) and 1.44 cm (STR1), while in calcareous soil, they were between 1.0 cm (control) and 1.42 cm (STR2).

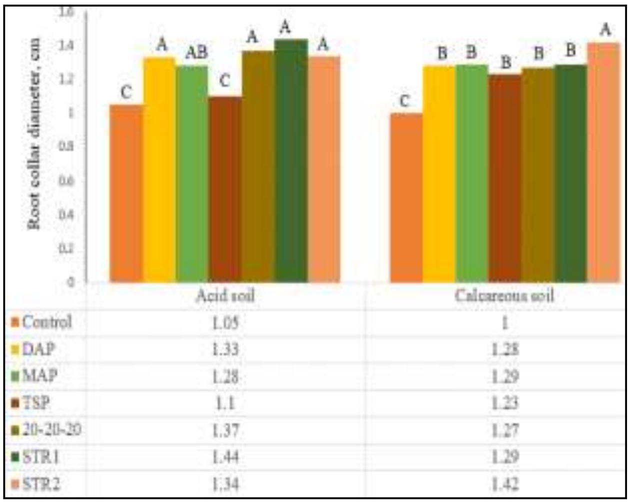

Figure 9. Effect of treatments on root collar diameter

Leaf Number and SPAD Value

The number of leaves on plants grown in acid soil ranged between 21.3 and 26.3, while in calcareous soil, it varied between 21 and 25.3 (Figure 10). In acid soil, the plants treated with TSP (21.3) and those in the control group control (22.0) had the lowest number of leaves, while the DAP-treated group had the most leaves (26.3). The effects of DAP and struvite applications (24.0 for STR1 and 24.7 for STR2) on the number of leaves were found to be partially in statistically similar. In calcareous soil, the control group with 21 leaves was the least effective treatment, followed by TSP and MAP applications with 22.7 and 23 leaves, respectively. The 20-20-20 fertilizer (25.3) was the most effective treatment for increasing lettuce leaf count, followed by DAP and STR2, and STR1, respectively. However, the effects of 20-20-20, DAP, STR2 and, STR1 were found to be statistically similar.

The effects of struvites and other chemical fertilizers on the SPAD values of lettuce leaves were found to be significant (P<0.01) in both acid and calcareous soils (Figure 11). In both types of soil, the leaves of the plants in the control application were in the lowest group in terms of leaf SPAD values. However, the STR1 was the most effective application at increasing leaf SPAD values in both soils. The SPAD value for plants grown under STR1 conditions was 27.8 and 28.9 for acid and calcareous soils, respectively. Although DAP, MAP, 20-20-20, and STR2 in acid soil, and DAP, 20-20-20, and STR2 in calcareous soil were not as effective as STR1, they were partially in similar statistical group with STR1.

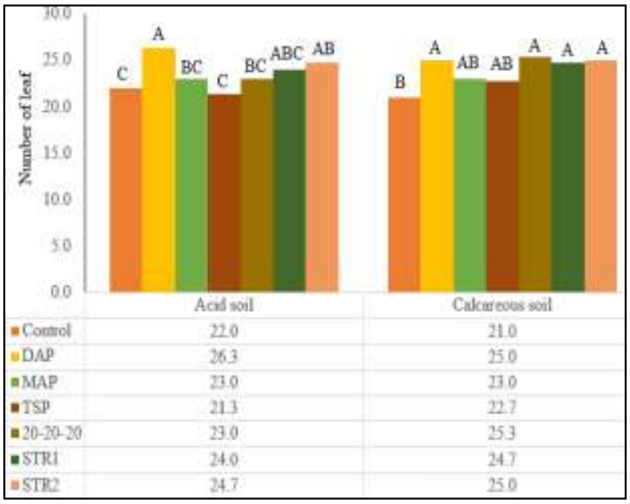

Figure 10. Effect of treatments on the number of leaves

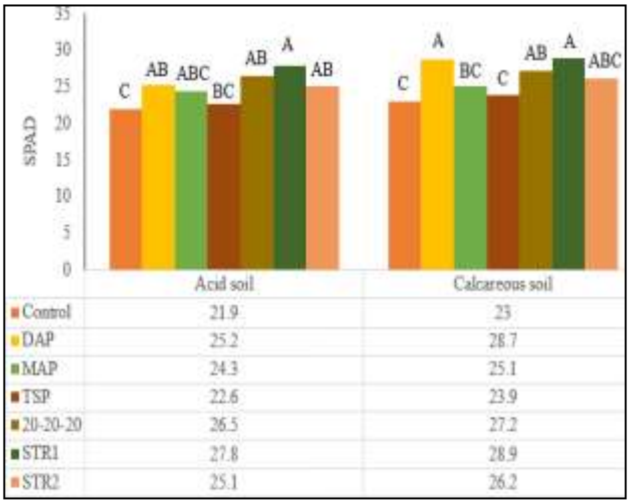

Figure 11. Effect of treatments on the leaf SPAD value of lettuce leaf

DISCUSSION

The results of the experiment showed that both struvite and chemical fertilizer applications had a positive effect on plant growth parameters, resulting in an increased lettuce head and root growth. The increases in lettuce head fresh yield and yield parameters indicated that struvites were found to be either superior or compatible with the chemical fertilizers used in the experiment. Similar results have been reported in previous studies on the effectiveness, compatibility, or superiority of different originated struvites on plant growth [9, 12, 22, 23]. In a study conducted by Siciliano [24], the impact of struvite precipitate on spinach growth under greenhouse conditions was investigated and compared to commercial fertilizers. The researcher observed that struvite fertilizer was found to be significantly more effective than a commercial complex fertilizer and the control group. The effectiveness of the struvites on head yield can be attributed to their nutrient contents. Although struvite is slightly soluble in water (1-5%) [25, 26], a much previous laboratory-based work has suggested that it is as effective as highly soluble mineral P fertilizer as a source of phosphorus for plants. One of the reasons for the effectiveness and superiority of struvites over most of the chemical fertilizers can be explained by their slow but sufficient release of nutrients [27]. Although the solubility of struvites is slow, some plants have the ability to produce some organic acids that enhance the solubility of struvite from roots. Lettuce is considered to be one of these plants [28]. The results showed that plants treated with struvite and composed fertilizer had shorter root elongation compared to other treatments. This may be due to the efforts of the roots to reach and access the deficient nutrient elements in the growing environment [29]. Although the roots are shorter under struvite and compound fertilizer applied conditions, their weights were close or even superior to other efficient fertilizers, especially under acid soil conditions. This indicates that the root structures of plants grown under struvite applied conditions are shorter but more denser. The superiority or equivalency of struvites in terms of leaf number and root collar diameter compared to composed fertilizers can be explained by the same reasons as observed in head weight, width, and height. While there are different perspectives on whether SPAD directly expresses the chlorophyll amount of the plant, estimating the chlorophyll levels by SPAD measurements is a common approach used by many researchers. Therefore, although direct chlorophyll measurement was not performed in the study, it is possible to say something about chlorophyll content just by looking at the obtained SPAD values. Accordingly, when the applications were evaluated, it was observed that the applied struvite, particularly STR1, showed a competitive performance especially with NP or NPK fertilizers, and even exhibited superiority. The likely cause of this situation may be explained by the presence of Mg and other nutritional elements other than N and P in the composition of struvite. As is well known, N and Mg are the main nutrients involved in chlorophyll formation [30, 31, 32]. Mg has a direct effect on the development of the plant and may enhance P uptake, thereby supporting increased plant growth through its synergistic effect with P [33, 34]. In another study, it was determined that struvite fertilizer (phosgreen), a commercial product derived from sewage waste, approximately doubled the chlorophyll levels in lettuce plant compared to superphosphate fertilizer. It has been stated that this increase may be attributed to the presence of N and Mg alongside to P in the phosgreen fertilizer [35].

In conclusion, both struvites examined in this study were found to be competitive and even superior to other commercial fertilizers in terms of plant growth parameters and SPAD values. Therefore, it is concluded that both struvites are valuable fertilizer sources for promoting and enhancing the growth of lettuce plant. In addition, it can be stated that struvite has different effects on different soil properties.

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