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Research Article

Evaluating Shrimp Shells as a Natural Soil Conditioner

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Abstract

Shrimp shell waste, a byproduct of the rapidly growing seafood industry, poses environmental challenges but also presents opportunities for innovative agricultural applications and research. This waste, generated from shrimp consumption, is typically disposed of through methods such as burning and burial. The aim of this study is to investigate the potential use of shrimp shells in agriculture and to investigate the impact of powdered shrimp shells as a cost-effective alternative to the chitosan on some soil physical properties. Shrimp shells were obtained from Kocaman Fishery in Bandırma. The shells were cleaned, dried, ground, and sieved through a 4 mm mesh to remove unground parts. The sieved soil was then mixed with the shrimp shells at weight ratios of 0%, 2%, 4%, and 6%. Following the incubation period, the water-holding capacity, porosity, bulk density, moisture content, field capacity, organic carbon, organic matter, pH, and electrical conductivity (EC) values of the samples were measured. In soils where shrimp shell powder was applied at varying rates, it was observed that the pH, electrical conductivity (EC), aggregate stability, organic carbon, organic matter, $CaCO_3$, water holding capacity, porosity, and field capacity values significantly increased with higher application doses. Consequently, shrimp shells can be ground into a powder and utilized as a soil organic conditioner at rates of 4% and 6%, while considering the pH and EC values of the soil.

Keywords: Shrimp shell, Field capacity, Soil physics, Organic matter, Organic carbon, Aggregate

Karides Kabuklarının Doğal Bir Toprak Düzenleyici Olarak Değerlendirilmesi

Öz

Hızla büyüyen deniz ürünleri endüstrisinin bir yan ürünü olan karides kabuğu atıkları, çevresel zorlukların yanı sıra yenilikçi tarımsal uygulamalar ve araştırmalar için de fırsatlar sunmaktadır. Karides tüketiminden kaynaklanan bu atık, tipik olarak yakma ve gömme gibi yöntemlerle bertaraf edilmektedir. Bu çalışmanın amacı, karides kabuklarının tarımda potansiyel kullanımını araştırmak ve kitosana uygun maliyetli bir alternatif olarak, toz karides kabuklarının bazı toprak fiziksel özellikleri üzerindeki etkisini araştırmaktır. Karides kabukları Bandırma'daki Kocaman Balıkçılık'tan temin edilmiştir. Kabuklar temizlenmiş, kurutulmuş, öğütülmüş ve öğütülmemiş kısımları ayırmak için 4 mm'lik bir elekten elenmiştir. Elenmiş toprak daha sonra karides kabukları ile %0, %2, %4 ve %6 ağırlık oranlarında karıştırılmıştır. İnkübasyon süresinin ardından örneklerin su tutma kapasitesi, porozite, hacim ağırlığı, nem içeriği, tarla kapasitesi, organik karbon, organik madde, pH ve elektriksel iletkenlik (EC) değerleri ölçülmüştür. Karides kabuğu tozunun değişen oranlarda uygulandığı topraklarda, pH, elektriksel iletkenlik (EC), agregat stabilitesi, organik karbon, organik madde, $CaCO_3$, su tutma kapasitesi, porozite ve tarla kapasitesi değerlerinin yüksek uygulama dozlarıyla önemli ölçüde arttığı gözlemlenmiştir. Sonuç olarak karides kabukları öğütüldükten sonra %4 ve %6 dozlarıyla, uygulamanın yapılacağı toprağın pH ve EC değerleri gözetilerek, toprak organik düzenleyicisi ve organik madde kaynağı olarak kullanabilir.

Anahtar Kelimeler: Karides kabuğu, Tarla kapasitesi, Toprak fiziği, Organik madde, Organik karbon, Agregat

Introduction

Soil organic matter, which consists of plant and animal residues, is directly linked to the physical, chemical, and biological properties of soil and serves as a key factor in determining soil quality. Organic matter has a significant impact on numerous soil physical properties, including aggregate stability, porosity, hydraulic conductivity, bulk density, field capacity, water-holding capacity, wilting point, soil aeration, and the improvement of undesirable attributes of soil texture and structure. Additionally, it enhances resistance to erosion. Consequently, organic matter is a crucial component for both soil quality and agricultural sustainability.

An analysis of the organic matter content in soils throughout Turkiye reveals that 18.04% of the soils had very low organic matter levels (less than 1%), whereas 70.51% are characterized by low organic matter content (ranging from 1% to 2%). This indicates that a significant portion of Turkish soil is deficient in organic matter (Tagem, 2018).

Various organic-based soil amendments-such as compost, green manure, biochar, and farmyard manure-can effectively address deficiencies in soil organic matter. However, these materials tend to mineralize shortly after application, necessitating continuous additions to the soil. Converting organic waste from agricultural activities or industrial production into compost through various methods, rather than incinerating and disposing of it, represents a sustainable recycling approach that enhances soil health, improves quality, and supports long-term agricultural viability. İşler et al. (2022) reported that composts made from olive pomace and vineyard pruning waste improved the aggregate stability of clay, loam, and sandy loam soils. Research indicates that the use of compost typically reduces soil bulk density, improves infiltration and hydraulic conductivity, and boosts water retention capacity (Kranz et al., 2020; Jain & Kalamdhad, 2020). Additionally, compost additions enhance soil organic carbon, organic matter, and nutrient levels and may also increase soil pH to neutral levels (Jain & Kalamdhad, 2020). Green manures and farmyard manures can improve soil structure by lowering bulk density and increasing overall porosity. Additionally, these practices benefit soil water properties, such as available water capacity, field capacity, wilting point, and moisture retention (Mujdeci et al., 2020). Mixing green manure plants into the soil provides a high content of nitrogen and other plant nutrients. Green manuring is regarded as an effective agricultural practice for improving soil organic matter and fertility (Balachandar et al., 2020). Kavdır et al. (2024) observed in their incubation study on sandy loam soil that biochar produced from olive pomace increased aggregate stability and total soil carbon.

Globally, mollusks account for 13% and crustaceans for 9% of fisheries and aquaculture production. Each year, approximately 8 million tons of crab, shrimp, and lobster shell waste are generated worldwide, representing up to 60% of the total crab biomass (FAO, 2021).

Chitosan is a natural soil enhancer that is favored over chemical alternatives. It is derived from chitin, a substance commonly present in the exoskeletons of crustaceans like crabs, lobsters, and shrimp, through a process called deacetylation. Shrimp shells are especially abundant in chitin, which is used to produce the chitosan polymer. The processing of shrimp generates in about 50-60% of solid waste, including by-products such as the head, viscera, and shells (Senphan & Benjakul, 2012). Studies have shown that chitosan application can improve soil water stability, permeability, and aggregate formation (Adamczuk et al., 2021). However, its impact on soil mechanical stability varies depending on soil texture and the characteristics of chitosan. In some soils, a decrease in strength and an increase in porosity have been observed (Adamczuk & Józefaciuk, 2022). Pichyangkura and Chadchawan (2015) observed that chitosan applied to soil significantly promoted seedling growth and triggered early flowering in several ornamental plants. Chitosan can serve as a carbon source for soil microorganisms, accelerating the conversion of organic matter into inorganic forms and facilitating greater nutrient uptake by plant roots. Additionally, chitosan can be used to add organic matter to soils without increasing the carbon-to-nitrogen (C:N) ratio (Xu and Mou, 2018). To produce chitosan, chitin is processed with a 40% sodium hydroxide solution, and more than 1000 liters of water are required to produce 1 kg of chitosan from shrimp shells (Yan & Chen, 2015). Due to its expensive production and high water requirements, in this study, dried and ground shrimp shells were used directly as shrimp shell powder (SSP).

Shell waste also has potential as an alternative soil amendment to lime, particularly for correcting soil acidity. For instance, ultrafine oyster-shell powder has been shown to increase soil pH and enhance calcium and magnesium contents in acidic soils (Du et al., 2016). Such amendments not only improve chemical properties but may also contribute to physical soil quality, as aggregate stability—an important indicator of soil health—reflects the ability of soil particles to resist disaggregation and maintain structural integrity. The chitinous composition of the shells contributes to the formation and stabilization of soil aggregates, which enhances pore space suitable for gas exchange and root growth (Gelybó et al., 2018). This improved aggregate stability can contribute to reduced soil erosion, increased water infiltration, and improved nutrient and water availability for plant growth.

Zhang et al. (2025) indicated that the combination of Ca-Mg-Si soil conditioner (SC2), earthworm manure (33.35 kg ha^{-1}), and shrimp shell meal (83.375 kg ha^{-1}) notably enhanced soil organic matter (SOM) to 5.52 g kg^{-1} and improved rice yields. Additionally, the soil dissolved organic matter (DOM) components exhibited a comparatively greater potential for carbon sequestration.

Dufault et al. (2001) conducted a study to assess the effectiveness of shrimp biosolid (SB) as a fertilizer for growing broccoli (*Brassica oleracea italica*), both on its own and in combination with inorganic fertilizers. The findings indicated that while SB can be beneficial as a fertility source, it does not optimize yield when used alone and should be paired with inorganic fertilizers. Additionally, due to the high sodium content in SB, caution is advised when using it alongside inorganic fertilizers for salt-sensitive plants.

The objective of this research is to consolidate the existing knowledge regarding the influence of crustacean shells on various soil characteristics, including soil properties, aggregate stability, soil pH and electrical conductivity (EC). Furthermore, the study seeks to explore the implications of these findings for the development of sustainable soil management practices.

Materials and Methods

The soil sample used in the experiment was collected from a depth of 0-20 cm using a shovel at the İncirlik location in Palamutoba village, Bayramiç district, Çanakkale province, with coordinates 39°51'29.9"N, 26°32'08.2"E. An undisturbed soil sample was collected from the surface at a depth of 0-5 cm using a steel sampling cylinder, following the procedures of labeling and placement in a plastic bag. Results of selected soil properties are presented in Table 1.

Table 1. Properties of the soil sample used in the experiment

pH	EC (ds m^{-1})	$CaCO_3$ (%)	Aggregate Stability (%)	Texture	Organic Matter (%)
7.52	0.323	5.4	9.32	Sandy Clay Loam	0.74

Shrimp shells (SS) have been obtained from Bandırma Kocaman Fisheries. The properties of the shrimp shells used in the experiment are presented in Table 2. The dried shells were ground using a Bosch brand grinder, passed through a 4 mm sieve, and turned into powder (SSP). The air-dried soil was sieved through a 2 mm sieve. SSP application rates were 0%, 2%, 4%, and 6% w/w and replicated three times. Each mixture was subsequently moistened to achieve half of the field capacity. The remaining soil mixtures were placed into the soil cores in specific volumes for Ksat measurements. All samples were incubated under controlled laboratory conditions, maintained at a temperature range of 20 to 25 °C, for 45 days. Water was added to the samples every 15 days, in accordance with the diminishing moisture levels.

Table 2. Properties of the shrimp shells used in the experiment

pH	EC (ds m^{-1})	Organic Matter (%)	$CaCO_3$ (%)
8.68	14.56	6.25	28.95

The methods used for the analysis of soils and shrimp shells, performed after incubation experiment are presented in Table 3.

Table 3. Methods of Analysis

Analysis	Method
Measurement of pH and EC	The pH values of the shrimp Shell (SS) were determined potentiometrically using a pH meter in a 1:10 soil:deionized water mixture, while the pH of the soil sample was measured in a 1:2.5 soil:deionized water mixture. Electrical conductivity (EC) was measured using an EC meter (Richards, 1954; Grewelling and Peech, 1960).
$CaCO_3$ measurement	It was determined using a Scheibler calcimeter (Allison and Moodie, 1965).
Organic carbon and organic matter	Smith and Weldon method (1941)
Aggregate Stability	The wet sieving method was used (Kemper and Rosenau 1986).
Soil texture	It was determined using the hydrometer method (Bouyoucos, 1951).
Porosity	Total porosity was determined by saturating a specific volume of soil and measuring it based on weight (Blake and Hartge, 1986).

Statistical Analyses

Statistical analyses were conducted using the Statistical Analysis System (SAS Institute, 1999). A one-way analysis of variance (ANOVA) was performed, followed by Duncan's multiple range test ($p < 0.05$), to evaluate the means of various rates of SSP on selected soil properties.

Results and Discussion

The pH value of the shrimp shells used in the experiment was 8.68, while the soil pH was 7.52 (Tables 1 and 2). As the rates of SSP added to the soil increased, the soil pH also increased significantly ($p < 0.0001$). However, the differences among the 2%, 4%, and 6% rates (Table 4) were found to be statistically not significant. Nkoh et al. (2023) observed in their study that the application of chitosan to acidic Ultisol soils increased soil pH in the range of 0.67–2.27. This pH increase was attributed to the ammonification of organic nitrogen and the mineralization of organic carbon. The extent of this increase may vary depending on soil type, with potentially greater or lesser effects observed in different soils. Similarly, Paz-Ferreiro et al. (2011) found that the addition of mussel shells increased soil pH compared to the control soil.

As the application rates of SSP added to the soil increased, the soil's electrical conductivity (EC) also significantly ($p < 0.0006$) increased (Tables 2 and 4). However, the differences between the 0% and 2% doses and between the 4% and 6% doses (Table 4) were not statistically significant. The EC value of the SSP used in our study was 14.56 dS m^{-1}, which contributed to an increase in soil EC. Rassaei (2023) observed in their study on clay-textured soil that chitosan applications at 0.5%, 2%, and 5% doses increased soil EC and pH levels. Similarly, Lee et al. (2008) found that the application of oyster shell powder increased the EC, pH, and SOC of both silty loam and sandy loam soils.

As the application rates of SSP increased, the soil $CaCO_3$ content also increased significantly ($p < 0.0020$). The differences among the 2%, 4%, and 6% doses were not statistically significant, although they were higher compared to the control (Table 4). Analysis revealed that the shrimp shells used in the experiment contained 28.95% $CaCO_3$ (Table 2) that contributed to the increase in soil $CaCO_3$ content. Ibrahim et al. (1999) reported that shrimp shells have generally high calcium content.

Table 4. The impact of varying application rates of shrimp powder on soil pH, EC, and lime content. Different letters within the same column indicate statistically significant differences at $p<0.05$.

SSP application rate	pH	EC (ds m^{-1})	$CaCO_3$ (%)
0%	7.52 b	0.32 b	5.4 b
2%	8.27 a	1.119 b	6.09 a
4%	8.36 a	1.552 a	6.28 a
6%	8.30 a	1.936 a	6.53 a

As the dose of shrimp powder added to the soil increased, a statistically significant increase in soil aggregate stability ($p< 0.0128$) and organic carbon content ($p<0.0001$) was observed. Similarly, as the dose of SSP increased, a statistically significant increase in soil organic matter was observed (p<0.0001). However, the difference in aggregate stability between 0% and 2%, as well as between the 4% and 6% doses, was found to not statistically significant (Table 5). Organic matter is an important factor that facilitates the aggregation of soil particles into aggregates. Studies have shown that mixing various organic matter sources such as chicken manure, compost, rice husks, and barn manure into the soil increases aggregate stability, soil organic matter, and soil organic carbon content (Fei et al., 2020; Rassaei et al., 2023; Das et al., 2014; Işler et al. 2022). Organic matter additions to the soil improve soil resilience by preventing the dispersion of soil aggregates when they interact with water (Rassaei et al., 2023). The high organic matter (6.25%) and organic carbon (3.63%) content of the shrimp powder used in the experiment (Table 2) increased aggregate stability and soil organic soil organic carbon content (Table 5).

Table 5. The impact of varying application rates of shrimp powder on soil aggregate stability and organic carbon content. Different letters within the same column indicate statistically significant differences at p<0.05.

SSP application rate	AS (%)	OC (%)
0%	11.81 b	0.51 c
2%	10.85 b	1.30 b
4%	20.87 a	1.44 b
6%	20.50 a	1.75 a

At a 2% dose of shrimp shell powder, bulk density (db) increased, while at a 6% dose, it was the lowest (Table 6) (p<0.0002). Although SSP was expected to reduce soil bulk density due to its inherently low bulk density, only the 2% dose showed a significant difference.

The water retention capacity at this application rate was also found to be reduced (Table 6). Soil bulk density is an indicator of soil compaction and porosity. An inverse relationship exists between bulk density and soil porosity, such that an increase in bulk density corresponds to a decrease in porosity. In soils characterized by elevated organic matter content, both aggregation and porosity tend to increase, resulting in a reduction of bulk density. Given that soil bulk density influences the pore space within the soil matrix, it plays a significant role in regulating water movement, aeration, and microbial activity within the soil ecosystem.

The two findings are mutually reinforcing, indicating that an increase in bulk density corresponds with a decrease in pore volume, resulting in a reduced capacity of the soil to retain water. Adamczuk et al., 2021, reported that the addition of chitosan significantly decreased the bulk density of soil aggregates. This is attributed to the lower particle density of chitosan compared to the solid phases of the soils examined.

Organic matter increases the soil structure and porosity, thereby enhancing its water retention capacity. As organic matter increases, the infiltration of water into the soil and the water retention within the soil also increase. After excess water is drained away from the soil, the amount of water retained field capacity is also positively correlated with the increase in organic matter.

As the SSP application rate increased to 6%, the soil water holding capacity significantly increased (Table 6) (p<0.0001). The lowest water retention capacity was observed at the 2% rate. There was a statistically significant difference among treatments in terms of water holding capacity (p<0.0001). The lowest field capacity value was found at the 2% application rate, while the highest value was observed at the 6% application rate.

When examining the effects of SSP on porosity, the differences among the applications were found to be statistically significant (p<0.0002). The lowest porosity value was observed at the 2% rate, whereas the highest value was found at the 6% application rate (Table 6). Hydrogels and superabsorbents derived from chitosan have shown promising results in improving the water retention capacity of soil, particularly in sandy soil. These substances can boost water retention, porosity, and field capacity (Jayanudin et al., 2022). As the soil organic matter increases, the particles in the soil cluster together, leading to enhanced aggregate formation. The aggregation of particles creates spaces within the soil, which in turn increases porosity. Studies have shown that higher organic matter content leads to more stable aggregates and the formation of larger pore spaces (Anonymous, 2021).

Table 6. The impact of varying application rates of shrimp powder on soil bulk density, water holding capacity (WHC), field capacity (FC), and porosity. Different letters within the same column indicate statistically significant differences at $p<0.05$.

SSP application rate	db (g cm⁻³)	WHC (%)	FC (%)	Porosity (%)
0%	0.99 b	57.96 b	54.16 b	57.49 b
2%	1.10 a	51.15 c	46.55 d	56.39 c
4%	1.03 b	57.59 b	51.86 c	59.04 b
6%	0.96 c	66.46 a	58.49 a	63.45 a

Conclusion

Following the 45-day incubation period, the results indicated that application of SSP increased soil $CaCO_3$ content, pH, and EC across all application rates compared to the control group. In this context, the application of SSP in soils with high pH, electrical conductivity (EC), and lime content is not recommended. The application of SSP has been shown to enhance SOC content of soils across all rates. A significant increase in soil aggregate stability has been observed at the 4% and 6% application rates. Based on these findings, SSP can be utilized as an amendment in soils that are low in organic matter and exhibit weak aggregate stability. The application of SSP led to a significant reduction in bulk density only at the 6% application rate when compared to the control group. Furthermore, statistically significant increases in water retention capacity, field capacity, and porosity were observed at the 4% and 6% application levels. The findings suggest that incorporating shrimp shell powder at concentrations of 4% and 6% positively impacts the physical properties of soil, demonstrating effects comparable to those observed with the more expensive biopolymer chitosan. However, this study did not investigate the impact of shrimp shell powder on soil microorganisms or its potential beneficial or detrimental effects on plant and soil health. Consequently, this research suggests that shrimp shell waste may serve as a viable source of organic matter and contribute to the improvement of the soil's physical and chemical properties.

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Authors' Contributions

Authors declare that they have contributed equally to the article.

Conflicts of Interest Statement

The authors declare that there is no conflict of interest.

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