Effects of Soil Compaction on Soil Carbon and Nitrogen Sequestration and Some Physico-Chemical Features
(Case Study: NorthofAqQala)

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ABSTRACT Soil compaction has become a widespread problem in the world and it is considered as one of the main factors affecting land degradation in arid and semi-arid agricultural land. The aim of this study was to investigate the effects of soil compaction on soil carbon and nitrogen sequestration, physical (aggregate stability, saturated soil moisture content, bulk density, and porosity) and chemical (EC, pH, organic carbon and nitrogen) features. The treatments were applied in the form of the completely randomized block design with four independent variables and three replicates. The study treatments included: control treatment (no artificial compaction), T₂ (2 times passing heavy tractor), T₃ (4 times passing heavy tractor) and T₄ (6 times passing heavy tractor). Toward this attempt, data was analyzed by means of the SPSS 16.0. Software package. The type of mean comparison method applied is the LSD test (at significant level of 5%). The results showed that different levels of soil compaction caused a significant effect on soil physical and chemical features. Based on the results, 6 times passing heavy tractor significantly reduced soil porosity and aggregate stability (respectively from 0.45% and 5.32 mm in control treatment to 0.25% and 3.88 mm) while this treatment (4) significantly increased soil bulk density as compared to other treatments (from 1.45 g cm⁻³ in the control to 1.97 g cm⁻³). Four and six times to-and-fro passing heavy tractor caused a significant reduction in soil carbon and nitrogen sequestration respectively from 3.26 t ha⁻¹ and 149.62 kg ha⁻¹ (in control) to 1.70 ton ha⁻¹ and 48.16 kg ha⁻¹ for T₃ and T₄ treatments, but significantly increased EC in comparison with other treatments (changed from 0.58 dS m⁻¹ in control treatment to 0.83 dS m⁻¹ in T₄). Also, all soil compaction treatments significantly increased soil pH. For example pH increased from 7.93 in control to 8.09 in T₄. While soil compaction treatments resulted in significant decrease in organic carbon, total nitrogen and saturated soil moisture values.

Key words: Artificial compaction, Land degradation, Soil feature

1 INTRODUCTION Soil compaction is a global problem and is considered an important form of physical degradation of land occurring in a wide range of soil types and climate conditions. This phenomenon causes a lot of changes in soil properties (Van Ouwerkerk, and Soane, 1994). Degradation caused by soil compaction is...
approximated as around 68 million hectares of land worldwide. The vast majority of modern agriculture soil compaction is caused by the passages of machineries (Flowers and Lal, 1996).

Soil is regarded as a sluggish renewable natural resource which conservation or degradation depends to a large extend on the way it is managed (Haj Abbasi et al., 1998). Selection of the type of device used in the tillage has effects on physical, chemical and biological soil attributes and thus crop yield (Tripathi et al., 2007).

Increased soil compaction arises from soil bulk density and penetration resistance growth. Reduction of the size of large pores, blockage of pores, soil surface crust formation and reduced aggregate stability, soil structure degradation, reduced soil porosity and permeability was considered as negative consequences of soil compaction (Al- Adawi and Reader, 1996). These negative consequences required additional fertilizer consumption and escalation of the cost of production. This create other consequences such as reduced plant growth resulting from less input of fresh organic matter to the soil, reduction of the recycling of organic matter and the mineralization process, reduced microorganisms activity, and depreciation of machineries. Compaction in dry conditions induces soil aridity stress and in high humidity conditions imposes less soil aeration, reduced availability of nutrients, decreased roots metabolic activity and finally reduction of plant growth and yield. Soil compaction was also reduced available potassium and nitrogen. This could increase the incidence of pests, resulting in added stress to crops and reduction of performance (Ahmad et al., 2006). For germination and growth of plants, a favorable level of water and nutrient should be available. Besides, for root penetration and germination soil should also be porous enough (Mosadeghi et al., 2000).

Changes in soil organic carbon is also an important indicator for estimating soil fertility and quality (Pathack et al., 2004). Carbon is stored in soil organic matter, but these reserves can be influence by different types of land uses. Agricultural operations, increases mineralization of organic material that leads to the withdrawal of soil carbon (to the atmosphere). Soil carbon due to the decisive role in determining the physical, chemical and biological soil attributes had a positive effect on soil quality and stability, crop production and environmental qualities. Transfiguration of pristine arable lands to agricultural fields, converts an important part of soil stable organic carbon to unstable form and hence increases soil organic material loss, excessive carbon oxidation and emission of carbon dioxide to the atmosphere (Jung, 2001). Conservative management systems can improve soil organic matter reserves and contribute to the reduction of atmospheric carbon (Zanatta, 2006).

Carbon sequestration using long-term operation of plant management not only increased carbon storage in soils but also reduced carbon exchange and CO₂ emissions. It also improved soil quality and production. Similarly, nitrogen fixation was able to reduce the rates and amounts of fertilizer applications (nitrogen fertilizer) and release of N₂O (another harmful greenhouse gases that causes global warming) (Upendra et al., 2008). Motavalli et al. (2003) also stated that the level of soil surface compaction reduces soil mineral nitrogen. Ventilation of poorly compacted soils reduced mineralization of organic matter which in turn reduced nitrogen and other elements biologic fixation. In addition, intensive denitrification in compacted with soil and nitrogen loss to the groundwater and the atmosphere was much more noticeable than the soil not compacted (Khallilian et al., 1991).

Soil organic matter, as one of the most important factor in soil quality, play important
role in the stabilization of the soil structure and improve the soil physical and chemical properties (Martel and Mackenzie, 1980). The improvement of soil aggregation was attributed to the increase in the organic matter. Organic matter is an important factor in soil aggregate stability since its size and various forms on soil be controllable through the optimal agriculture management (Bardgett and Shine, 1999), thus it could have an influence on the effective processes in the soil aggregation (Abiven et al., 2007).

Unsuitable and indiscriminate agricultural operations break the coarse aggregate sand put the soil organic matter at risk of destruction (Steiner et al., 2007). So soil aggregates dispersion leads to a crust forming on the soil surface that this caused reduced permeability and increased runoff (Karimi et al., 2008).

The effect of salinity and alkalinity which is caused by the presence of high exchangeable sodium can lead to the destruction of soil structure (Barzegar, 2001). Soil degradation in the first place is affected by natural factors, lurking weakly in the background, which is intensified by improper agricultural activities and manifest itself through soil salinity (Jafari, 2000). Problem of soil salinization in agricultural activities is a major problem facing mankind throughout the history. Agricultural operations can directly cause soil salinity. Anything that increases soil salinity can lead to land degradation and push the land towards desertification. Therefore, one must consider factors and the manner they alternate.

Currently, environment protection and achieving sustainable development is one of the pressing issues being highly appreciated through comprehensive economic, social and cultural evaluation plans in different countries of the world including our country. Soils of the study area (north of the Aqqala city) could be classified as arid and semi-arid soils. The use of heavy machinery for agriculture and plowing at a constant depth in this area for many years has increased the density of surface or subsurface layers (in the root growth zone). The study on the impact of environmental stresses can reveal ways to increase product performance and ensure stable production (Asgari, 2008). So, this study is aimed at quantifying the effects of soil compaction on carbon and nitrogen sequestration in wheat along with physical and chemical properties of soil as significant parameters in sustainable production.

2 MATERIALS AND METHODS

The study area is located in the northwest of Golestan Province. A part of the northern fields of Aq qala town ship was selected as the case study. The farms expanded from 37° 04’ 36” northern latitude to 54° 27’ 24” eastern longitudes. The relief of the area ranges between 46 to 21 meters above the sea level.

In the first experiment, artificially subsurface compaction was performed by means of a tractor of the SAME LASER 150 model, weighing 5,700 kg with 26 in 52 meters in diameters (the land was completely flat with no gradient). Next, the 0.1m of topsoil was prepared by soft disking for seeding. The experiment with 4 treatments and 3 replications was conducted as follows:

i) T1: Control treatment (without artificial compaction): chiseling + shallow disking to a depth of 10 cm
ii) T2: two passings heavy tractor + shallow disking to a depth of 10 cm
iii) T3: four passings heavy tractor + shallow disking to a depth of 10 cm and
iv) T4: six passings of a heavy tractor + shallow disking to a depth of 10 cm (Figure 1).
At the time of the creation of artificial compaction, soil moisture was 21%. Use of agricultural inputs (chemical fertilizer application rates, herbicides, etc.) was the same for all treatments. Prior to cultivation and based on the recommendation made by the extension commissioners, 160 kg ha\(^{-1}\) phosphorus, 160 kg ha\(^{-1}\) potassium and 50 kg ha\(^{-1}\) nitrogen fertilizers were applied to the fields. Because dry farming was the common agricultural practice in the study area, so the precipitation received (Mean precipitation 339 mm) to all parts of treatment plots was the same.

Traits studied in this experiment are as follows: soil’s carbon and nitrogen sequestration, soil physical (aggregate stability, saturated soil moisture content, bulk density and soil porosity) and soil chemical (EC, pH, organic carbon and nitrogen) properties.

Soil bulk density is determined by a core sample (Klute, 1986). Total porosity was worked out using the same soil samples those were collected for soil bulk density. Total porosity (%) was calculated by using the following formula (Equation 1, 2).

\[
\text{Total porosity} = 100 - (\text{B.D}/\text{P.D} \times 100)
\]  

\[
\text{P.D} = \frac{\text{Mass of soil sample}}{\text{Volume of water displaced}}
\]

The mean weight diameter of aggregates (MWD) was obtained by using following equation (Equation 3) (VanBavel, 1949):

\[
\text{MWD} = \sum_{i=1}^{n} \text{XiWi}
\]  

where ‘x’ was the average diameter of the openings of 4 consecutive sieves, and ‘W’ was the weight ratio of aggregates remaining on the ‘i’ sieve.

Soil organic matter was measured by wet oxidation method (Nelson, 1982). The percent of nitrogen in soil was calculated by using the obtained percent of carbon (Equation 4):

\[
\text{Total Nitrogen} = \text{percent of organic matter} \times 0.05
\]  

The amount of pH and EC are determined by pH meter and EC meter in saturated mud.

The obtained final experimental data were analyzed by SPSS 16.0. Statistical software. Treatment means were compared with LSD test at 1% level.

3 RESULTS AND DISCUSSION
The results showed that soil compaction has a significant impact on all physical and chemical parameters. The effect of treatment 4 (6 times...
passing heavy tractor) on all measured parameters was significantly higher than other treatments.

3.1 Soil physical features
The result of variance analysis was showed in Table 1. Comparison of mean measured parameters showed significant differences in some parameter at 5 and 1% level in 0-20 cm soil depth due to increasing compaction. Table 2 summarized effect of subsoil compaction on soil physical properties.

3.1.1 Soil bulk density and total porosity
Comparison of mean bulk density (Table 1) showed that increasing soil compaction has been caused an increase in soil bulk density. The result showed that minimum (1.45 g cm\(^{-3}\)) and maximum (1.97 g cm\(^{-3}\)) of bulk density was belong to control treatment and treatment 4, respectively. There was no significant difference between 2 and 4 to-and-fro tractor treatments and only 6 times to-and-fro treatment had a significant effect on soil bulk density. Soil bulk density in 2, 4 and 6 times to-and-fro treatment increased 21, 8 and 39% in comparison to control treatment (Table 1). Similar trend was observed for total porosity. Maximum porosity reduction (25%) caused via T\(_4\) where six passes of tractor were applied. The results of this study were confirmed with researches of Hasan \textit{et al.} (2007), Al-Adawi and Reader (1996), Bouwman and Arts (2000), Motavalli \textit{et al.} (2003) and Baiat \textit{et al.} (2005). They stated that other physical parameters are affected by increase of soil density and compaction so that aggregate is closed together and is removed soil coarse pores. Aggregate sticking to each other causes decreasing porosity and increasing soil bulk density (Elliot, 1986). Bertolino \textit{et al.} (2010) stated increase of bulk density is due to reduction of soil coarse pores and reduction of total soil volume subsequently. Raza \textit{et al.} (2005) reported that soil density causes increasing amount of bulk density in tillage layer significantly.

<table>
<thead>
<tr>
<th>Variation sources</th>
<th>Degree of freedom</th>
<th>Soil bulk density (g cm(^{-3}))</th>
<th>Porosity (%)</th>
<th>Aggregate stability (mm)</th>
<th>Soil saturated moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2</td>
<td>0.003</td>
<td>0.005</td>
<td>0.204</td>
<td>0.001</td>
</tr>
<tr>
<td>Soil Compaction</td>
<td>3</td>
<td>0.155*</td>
<td>0.022*</td>
<td>1.322*</td>
<td>0.009**</td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td>0.045</td>
<td>0.006</td>
<td>0.188</td>
<td>0.001</td>
</tr>
</tbody>
</table>

** Significant at 1% level, * significant at 5% level, ns: non-significant

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Soil bulk density (g cm(^{-3}))</th>
<th>Porosity (%)</th>
<th>Aggregate stability (mm)</th>
<th>Soil saturated moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.45*</td>
<td>0.45*</td>
<td>5.32*</td>
<td>0.67*</td>
</tr>
<tr>
<td>2 Times passing of tractor</td>
<td>1.57*</td>
<td>0.36*</td>
<td>5.24*</td>
<td>0.59*</td>
</tr>
<tr>
<td>4 Times passing of tractor</td>
<td>1.75*</td>
<td>0.38*</td>
<td>4.68*</td>
<td>0.56*</td>
</tr>
<tr>
<td>6 Times passing of tractor</td>
<td>1.97</td>
<td>0.25*</td>
<td>3.88*</td>
<td>0.55*</td>
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</tbody>
</table>

In the table Letters a, b, c, d indicates significant levels. Treatments with different letters have a significant difference with together
3.1.2 Aggregate stability (MWD)
The results showed that all soil compaction treatments significantly decreased soil aggregate stability as compared to control. However, T4 had significantly higher negative effect on MWD (As an indicator of the aggregate stability) in comparison to control and also other soil compaction treatments (MWD changed from 5.32 mm in control to 3.88 mm by T4) (Table 1).

The effect of soil compaction on aggregate stability has been investigated in several studies. Carter (1998) stated that decrease in aggregate stability implies the unstable use of land. Aggregate dispersion leads to creating a crust on the soil surface and subsequent infiltration reduction. This, subject affects soil conductivity and soil stability to retain air and water (Karimi et al., 2008).

3.1.3 Saturated soil moisture
The results indicated that the effect of all soil compaction treatments have caused a significant reduction on saturated soil moisture values. Saturated moisture percentage was reduced from 0.67% in control to 0.55% in T4 where six passing tractor was applied. Similarly, T2 and T3 resulted in lower saturated moisture (0.59 and 0.56%, respectively, via T2 and T3) as compared to control (Table 1).

The effect of soil compaction on saturated moistures largely governed by larger pores (Ehlers, 1983; Lin et al., 1996, 1999; Lipiec et al., 1995), which are negatively related to soil compaction (Carter, 1998).

Gysi et al. (1999) reported that moist soil responded at a depth of 12-17 cm to a ground contact pressure with an increase in bulk density and consolidation pressure, as well as with a decrease in air permeability and macroporosity. Degradation of soil aggregates and pores among and decreased of soil aggregates stability in turn leads to reduced water infiltration into the soil (Horn et al., 1995).

3.2 Soil chemical features
Variance analysis showed a significant difference among different levels of compaction on soil carbon and nitrogen sequestration, pH and EC (Table 3).

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Variance analysis of chemical parameters in different treatments of compaction</th>
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<tbody>
<tr>
<td>Variation sources</td>
<td>Degree of freedom</td>
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<tr>
<td>Frequency</td>
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<tr>
<td>Soil Compaction</td>
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<td>Error</td>
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**Significant at 1% level, *significant at 5% level, ns: non-significant

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<th>Table 4</th>
<th>Effect of subsoil compaction on some soil chemical properties</th>
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<tr>
<td>Treatments</td>
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<tr>
<td>Control</td>
<td>1.65 a</td>
</tr>
<tr>
<td>2 times passing tractor</td>
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<td>4 times passing tractor</td>
<td>0.87 c</td>
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<td>6 times passing tractor</td>
<td>0.6 d</td>
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In the table letters a, b, c, d indicates significant levels. Treatments with different letters have a significant difference with together
3.2.1 Organic carbon and total nitrogen
The results indicated that the effect of soil compaction on soil organic carbon, total nitrogen in all treatments was significant and carbon and nitrogen sequestration was significant in T$_3$ and T$_4$ (P <0.05). Soil compaction decreased soil organic carbon and total nitrogen respectively from 1.65 and 0.12% (in the control) to 0.6 and 0.07% by T$_4$ (Table 4).

Carbon and nitrogen sequestration also decreased significantly with increasing soil compaction levels. So that sequestration of carbon and nitrogen was reduced from 48.07 ton ha$^{-1}$ and 4.14 ton ha$^{-1}$ in the control treatment to 23.87 and 2.05 ton ha$^{-1}$ in T$_4$, respectively (Figures 2 and 3).

**Figure 2** Effect of soil compaction on soil carbon sequestration

**Figure 3** Effect of soil compaction on soil nitrogen sequestration
Golchin et al. (1994) stated that by the effects that soil compaction leaves on the formation of aggregates, the level of soil carbon is also affected. By reducing the access of enzymes to the materials within the soil aggregate, soil organic matter is physically maintained. Wright and Hans (2005) also concluded that agricultural land management practices increase carbon and nitrogen sequestration in the soil. Maximum (8.09) and increased significantly in all levels with mean comparison showed that pH rate management of lands (NRCS, 1998). Soil acidity may be changed due to different primary reasons for changes in N availability in compacted soils are: decreased soil aeration resulting in increased denitrification, reduced N mineralization and decreased symbiotic N fixation; changes in soil water properties affecting N transport and leaching and; changes in soil structure altering root dynamics (Lipiec and Stepniewski, 1995). In addition, soil nitrate degradation in compacted soil and nitrogen losses to groundwater and in the atmosphere in this soil more than non-compacted soil(Khalilian et al.,1991).Soil compaction through its effect on soil aggregates may have negative effect on soil organic carbon (Golchin, 1994).

3.2.2 Acidity
Soil acidity may be changed due to different management of lands (NRCS, 1998). The results of mean comparison showed that pH rate increased significantly in all levels with increasing compaction. Maximum (8.09) and minimum (7.93) amount of pH were obtained in treatment 4 and control treatment, respectively (Table 1). The increase of pH prevents of creating aggregate by increasing the critical concentration of coagulation and lead to collapse of minerals and release of cations. Increase in soil pH also causes aggregates degradation, swelling and dispersion of clay particles, crusting and reducing porosity and permeability (Landy, 1994). Horn and Franzluebbers (1996) and Dick (1983) reported soil pH increased by intensity of agricultural and tillage operation because of different processes such as mineralization organic matters, increasing nitrification and root exudation.

3.2.3 Electrical conductivity
The results of mean measured EC in different levels of compaction showed the lowest (0.58) and highest (0.83) rate of EC are belonging to control and 4 times to-and-fro treatments respectively (Table 1). Also the effect of treatment 3 (4 times to-and-fro) and treatment 4 (6 times to --and-fro) on soil EC was significant. Baker and Nie (1994) reported that increasing agricultural activity increases the electrical conductivity of the soil and with decreasing water absorption by the roots, reduces photosynthesis in plants and thereby affect the operation of the plant. Westcot and Ayers (1985) also concluded that salinity affects on available water for plant in soil and reduces its performance and thereby crop production and cultivation in many part of the world is a risk (Ekez and Yilmaz, 2003). Salinity also causes an imbalance of available nutrient in salinity soils and is limited plant growth (Qadir, 2004; Asgari et al., 2013b). With increasing salinity, is reduced carbon accumulation, net assimilation rate and dry matter yield, the ratio of dry weight root to stem, leaf area, plant height and amount of perspiration (Bernard et al., 2000). Shabanpour et al. (2011) concluded that in non-saline soils plant resist against highly soil compaction but with increasing salt and compaction, absorption rate of elements strongly reduced.
4 CONCLUSION
Recent advances in upgrading agricultural production in the field in an intense manner bring about unwelcome changes in ecology, sociology and economy. From the latter one might include soil erosion, soil salinity, soil quality and quantity deterioration, soil contamination with agricultural chemicals, depreciation of social structures, weakening the economic power of traditional societies and phenomena like these.

Soil compaction can also have a severe negative effect on agricultural crop production. In total, even low levels of soil compaction (the treatment of two passings heavy tractor) is able to remarkably alter soil physiochemical attributes and thus carbon and nitrogen sequestration in soil. In nitrogen and carbon sequestration levels are important for who concerned of global warming and climate change.

Intensified mineralization of organic carbon and wasting soil organic content and their related nutrients can be done through collapse of aggregates and degradation of soil organic storage, which are under protection of fine aggregates.

In present study, by increasing compaction, aggregate stability was reduced so that MWD reduced from 5.32 mm in control treatment to 3.88 mm in T4 which in turn decreased soil organic content. Breaking the balance between the processes of humus formation and mineralization leads to reduction of available Nitrogen that its negative effects are considered on cation exchange capacity.

In this research, organic carbon and total soil nitrogen respectively were reduced from 1.36 and 0.12 in control treatment to 0.78 and 0.07 in T4. Obviously, results of this study showed that the negative effects of soil compaction on soil physiochemical properties. Soil physical and chemical properties are negatively affected include: increasing EC and pH from 0.58 and 7.93 in control to 0.83 and 8.09 in T4, respectively. Moreover, a significant reduction in saturated soil moisture percentage was observed (from 0.67 in control to 0.55 in T4).

Since soil compaction, especially in the deeper layers is not easily resolved, prevention is the best way to tackle the problem. Regarding the inability of deactivating soil compaction adverse effects in the deep soil layers of agricultural fields is the best way of handling and preventing soil compaction. Using these sluggish renewable resources should be consistence with land capability and its physical nature. This type of land use will result in sustainable development. From the remarks given here, it might be concluded that revising agricultural regimes and production methods is inevitable. On this ground, revisiting current agricultural systems should be considered and an urgent demand for state of the methods consistent with environmental objectives is being felt.

5 ACKNOWLEDGEMENT
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<tr>
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تأثیر فشردگی خاک بر ترسيب کربن و نیتروژن در خاک و برخی خصوصیات فیزیکی و شیمیایی خاک

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چکیده

فشردگی خاک به یک مشکل فراگیر در سطح دنیا تبدیل شده و یکی از عوامل مهم در تخریب اراضی به‌خوبی در کشاورزی مناطق خشک و نیمه خشک به‌شمار می‌رود. هدف از این تحقیق بررسی تأثیر فشردگی خاک بر توان ترسيب کربن و نیتروژن در خاک و خصوصیات فیزیکی و شیمیایی خاک به‌شمار می‌رود. برای مقایسه کلیه این خصوصیات به‌صورت کلیه با استفاده از آزمون LSD احتمال ایجاد اختلاف بین تیمارهای مختلف کشت در خاک، اطلاعات از استاندارد SPSS ۱۶ و SPSS به کار گرفته شد. در این تحقیق، برای تثبیت اختلافات بین تیمارهای مختلف به‌دست‌آمده از طریق چهار تحلیل آماری (اصولی، رتبه‌گذاری، تحلیل و تجزیه‌بندی) انجام شد. نتایج نشان داد که سطوح مختلف فشردگی خاک باعث افزایش میزان جرم مخصوص ظاهری خاک در جریان فشردگی خاک می‌شوند. همچنین، نشان داد که تأثیر تفاوت‌های فشردگی خاک بر توان ترسيب کربن و نیتروژن در خاک قابل توجهی دارد. در این تحقیق، هر یک از تیمارهای مختلف به‌طور محتوایی خاک و اثرات ویژگی‌های خاک به‌صورت جداگانه محاسبه گردید. نتایج نشان می‌دهد که تفاوت‌های مختلف فشردگی خاک باعث افزایش میزان جرم خاک در جریان فشردگی خاک می‌شوند. همچنین، نشان داد که تأثیر تفاوت‌های فشردگی خاک بر توان ترسيب کربن و نیتروژن در خاک قابل توجهی دارد.

مطالعه موردی

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کلمات کلیدی: تخریب سرزمین، خصوصیات خاک، فشردگی مصنوعی

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