Response of microbial community in the arid land to wheat residues and soil compaction

استجابة التجمعات الاحيائية في الترب الجافة الى مخلفات الحنطة ورص التربة

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Abstract

This study was conducted to evaluate the effect of soil compaction and wheat residues on microbial activity, bacterial abundance, fungal abundance, organic carbon and mineralisation constant following two months of pots incubation at the College of agriculture, AL-Qasim Green University in Iraq. Compaction level was induced by hummer drop to bulk density of 1.70 g/cm^3. Results proved overall that microbial activity, total bacteria, total fungi and organic carbon increased significantly after addition of wheat straw only. Soil compaction overall reduced significantly microbial activity, total bacteria, total fungi and limited the mineralization process in soil as compared to the non-compacted soil. However, soil compaction did not significantly affect organic carbon in the compacted soil in a comparison to the non-compacted soil. The application of wheat straw to the compacted soil maximized the microbial activity, total bacteria, total fungi and mineralization constant compared to the compacted control treatment. The percentages of rehabilitation of compacted soil were 28%, 85 %, 66 %, 10% and 20 % for microbial activity, total bacteria, total fungi, organic carbon and mineralization constant respectively. This study demonstrates that soil compaction minimised soil microbial community and this status can influence soil nutrient cycle. Furthermore, the amendments of wheat residue to the compacted soil may enhance soil microbial community and decomposition process. More importantly, the response of bacterial community to plant residues in the compacted soil was higher than fungal community indicating that bacterial community is more resistant and resilient to the disturbance of logging in the arid land.

Keywords: soil compaction, microbial activity, organic carbon, bacterial and fungal abundances.

الخلاصة

يعتبر رص التربة بشكل عام احد المشاكل الكبيرة التي تؤثر على تجمعات الاحياء المجهرية في التربة . ان التداخل بين رص التربة والمخلفات العضوية وتجمعات الاحياء المجهرية في الترب الجافة في العراق لم يدرس بصورة واسعة. هدفت هذه الدراسة الى فحص تاثيرالمخلفات العضوية ورص التربة على نشاط الاحياء المجهرية ، اعداد البكتريا ، اعداد الفطريات ، الكاربون العضوي اضافة الى معدنة الكاربون العضوي في اصص حضنت لمدة شهرين في البيت البلاستيكي التابع لكلية الزراعة – جامعة القاسم الخضراء . بينت النتائج بان اضافة مخلفات الحنطة ادى الى زيادة عالية المعنوية في نشاط الاحياء المجهرية، اعداد البكتريا ، اعداد الفطريات والكاربون العضوي في التربة . ان رص التربة ادى الى تقليل نشاط الاحياء المجهرية ، اعداد البكتريا والفطريات اضافة الى تقليل معدنة الكاربون العضوي . ان اضافة مخلفات الحنطة الى الترب المرصوصة ادى الى زيادة نشاط الاحياء المجهرية ، اعداد البكتريا والفطريات اضافة الى معدنة الكاربون العضوي مقارنة مع الترب المرصوصة لمعاملة المقارنة . كانت نسب اعادة تاهيل الترب المرصوصة 28% ، 85% ، 66% ، 10% و 20% وقد تضمنت النسب نشاط الاحياء المجهرية واعداد البكتريا واعداد الفطريات والكاربون العضوي وثابت المعدنة على التوالي تبين كذلك بان رص التربة ادى الى تقليل نشاط الاحياء المجهرية وانعكاسات ذلك على دورة العناصر الغذائية في التربة . بينت الدراسة ايضا بان اضافة المخلفات العضوية الى الترب المرصوصة ادى الى تحسين نشاط الاحياء المجهرية وعملية التحلل. ان استجابة التجمعات البكتيرية للمخلفات العضوية في الترب المرصوصة كان اعلى من نظيرتها الفطريات التي تعتبر مؤشر مهم على مقاومة البكتريا لظروف الاجهاد العالي في الترب الجافة وانعكاسات ذلك على تحليل المخلفات العضوية .

Introduction

The application of modern agriculture requires intensive employments of agricultural equipment for soil handling, fertilizer, pesticide application and harvesting which cause a considerable decline in future soil productivity (1). The operations of intensive harvesting can effect soil compaction, soil surface structure degradation, and decreased nutrient availability due to biomass removals or erosion and increased sediment yield as a result of erosion (2, 3). Furthermore, the process of harvesting requires the use of heavy machines, causing severe compaction of the soil particularly during wet conditions and along skid trails and landings (4, 5). The loads of agricultural machinery can change the soil physically and reduces plant productivity as a result of compaction (6).

Soil compaction is a key disturbance for soil properties. Soil compaction increases soil bulk density and decreases soil porosity and infiltration capacity (7, 8). Changes in soil porosity affect water infiltration, air permeability, temperature, rooting space, nutrient flow and biological activity (7, 9, 10, 11), often are resulting in increased surface runoff, soil erosion, nutrient leaching and greenhouse gas emission (12, 13). The soil system in turn can suffer substantial and persistent destruction, which leads to reduction in forest productivity and ecosystem functionality.

There is a complex relationship between compaction and soil microorganisms in soils. Microbial activities are sensitive to the environmental fluctuations. Compaction can influence the plant-available nutrients due to a reduction in number and activity of microorganisms in soil (14). Soil compaction can shift soil conditions towards anaerobic state that is associated with reduced aerobic microbial activities, increased denitrification rates, and reduced uptake of nutrients as a prelude to reducing plant growth (7, 9). 15 found the soil compaction reduced microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), soluble organic C and N on several sampling dates. Besides the carbon mineralization was reduced by soil compaction. Likewise, (16) reported the populations of bacteria, total fungi, nematodes, and arthropods were significantly decreased in compacted soil compared to the control. However, few studies have found significant effects on microbial properties (17, 18, 19), or non-significant effects (20, 21, 22, 23, 24, 25, 26). For example (27) found that soil compaction increased ^{14}C-CO_2 release from a silt loam soil with addition of ^{14}C-labeled wheat straw. This result can indicate that there is a higher energy demand for C assimilation under anaerobic conditions which were created by soil compaction. Furthermore, these notes can also signal that microbial communities exhibit high degrees of resistance and resilience to compaction and might not adequately reflect the ecological consequences. Similarly, (28) found that microbial activity was increased under no tilled soil compared with tilled soil and attributed that to the interaction between moisture content, organic carbon and microbial activity which might have improved its activity.

By adding plant residues to soil, these means can prevent soil compaction, provide nutrients, increase soil cation exchange capacity, maximise microbial biomass and fungal hyphal length and improve water retention in badly degraded sandy soils (7, 29, 9, 30, 31, 32, 33). However, there are no studies in arid land (Iraq) focusing on the effects of compaction on biological properties and processes in degraded soils, where plant residues are incorporated into the soil. Therefore, the objective of this study was to evaluate the effect of compaction and wheat residues on the soil microbial community and decomposition process.

Materials and Methods

The study site is located at the College of agriculture, AL-Qasim Green University, (32°23'34.3"N, 44°24'07.8"E) which located at about 10 km south of the Hillah city in Iraq. The average annual rainfall is (101 mm), the average annual temperature is (30.1Co) and the average value of Relative Humidity is (49.4 %). The studied area classed as Arid – Desert- hot region (BWh) according to (34) climate classification. Soil texture is silty clay loam (39 % clay, silt 43 %, sand 18%). Bulk density of soil is 1.40 g/cm^3. The electric conductivity is 5.40 Ds/m. pH is 7.40.

Soil samples were collected from the top 30 cm and air-dried and sieved before applying the compaction to remove rocks and small stones. Wheat straw was chopped to less than 1cm and mixed thoroughly with 10 kg dry soil in pots. 1% wheat straw was added to soil. Wheat straw contained 47% organic carbon, 0.5% nitrogen, 94 C/N ratio, 39 % cellulose and 8% lignin. There were a total of four treatment combinations (non- compacted control treatment, compacted control treatment, non- compacted plant residues treatment, and compacted plant residues treatment).

In order to obtain a good degree of compaction, soil was adjusted to 0.35 gram H_2O per gram of soil (3500 ml per pot) and equilibrated for 1 day before compaction. The soil was uniformly compacted manually using heavy drop hammer to a bulk density of 1.70 g/cm^3. The non-compacted control soil received no compaction and its bulk density was 1.40 g/cm^3. Soil bulk densities were determined by the core method (35). Pots were incubated for two months in the green house at 25 C°. Pots were weighed gravimetrically to determine the suitable quantity of water (1000-1500ml pot^{-1}) to add to the compacted and non-compacted treatments.

Measurements

a- Basal Respiration by static alkali method

20 g of soil was placed inside a flask corked with a stopper to which a 10 ml glass bottle was attached. The bottle was filled with 5 ml solution of 0.62M NaOH. The NaOH solution captured any CO_2 that was respired from the soil.

0.5 M HCl was used to neutralize 5 ml of NaOH containing a phenolphthalein indicator, the addition of three drops of the indicator into the NaOH solution caused a colour change to pink. The endpoint of the titration was when the pink colour was changed to pale. The amount of carbon dioxide evolved in soil respiration was estimated based on(36).

$$\mathbf{CO_2}\left(\frac{\mathbf{mg}}{\mathbf{g}}\right) = \frac{\mathbf{(B - V)N22}}{\mathbf{w}}$$

where B = standard HCl used to titrate NaOH in the blank (mL), V =standard HCl used to titrate NaOH in the treatment (mL), N = normality of HCl (1.00 N), 22 = equivalent weight of CO_2, W = dry weight of soil in the chamber (g).

b- Soil microbial populations

The samples were processed using soil dilution plate method (37). One gram of soil sample was serially diluted with sterilized water up to 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6} and 1 ml of each dilution was added to 20ml of nutrient agar medium (Tryptic-soya agar) in 90mm diameter sterile petri dishes to enumerate bacterial colony and using Martin's Rose Bengal agar for fungal colony. Data were expressed as the number of colony-forming units (CFU g^{-1} of dry soil). Bacterial plates were incubated at 28°C for 3 days and fungal plates at 25°C for 7 days prior to enumeration of viable colonies. To calculate the number of bacteria and fungi per gram of diluted sample, equation below should be used:

Viable cells / g dry soil = (Mean plate count * Dilution factor) / Dry weight of soil (g)

c- Organic carbon

Soil organic carbon was estimated by the muffle furnace method (38). Soil was passed through 2 mm sieve. 10 g of soil was placed into a crucible after recording its weight. Crucibles placed into 105 C° oven over-night. All crucibles then were reweighed after taking them from the oven. Crucibles were placed into a muffle furnace and ignited at 400 C° for 16 hours. Crucibles were taken out and reweighed again.

The percentage of loss ignition was calculated as follow:

$$\%\ \mathbf{loss\ ignition} = \frac{\mathbf{(oven\ dry\ soil\ weight - ignited\ soil\ weight\ )}}{\mathbf{(oven\ dry\ soil\ weight)}} \times \mathbf{100}$$

Soil organic matter which was calculated from the above equation was divided by 1.724 to obtain the percentages of soil organic carbon (39). This Van Bemmelen factor is based on the assumption that organic matter is 58% of carbon (100/58= 1.724) (40).

d- Mineralization constant

A mineralization constant was calculated by dividing basal respiration –C to organic carbon (41). This ratio was measured to indicate the organic carbon decomposition in soil after application of plant residues and compaction. The calculations of mineralization constant as fellow:

$$\textbf{Mineralization constant (mg } CO_2 - C\ g^{-1}\ h^{-1}\textbf{)} = \frac{\text{basal respiration}}{\text{organic carbon}}$$

Statistical analysis

The data were analysed using Minitab version 14. ANOVA analyses (two-way ANOVA) tested for treatment (non- compacted control treatment, compacted control treatment, non- compacted plant residues treatment, and compacted plant residues treatment) and compaction with six replications. Differences between means were further evaluated where significant treatment effects were obtained using Tukey's Studentized range (HSD) test with a significance level of $P < 0.05$.

Results and Discussion

1- Effect of compaction and wheat residues on microbial activity and CO_2 efflux

Microbial activity was increased significantly from 33.17 mg /g in the control to 51.17 mg /g after addition of wheat straw. Plant materials contain carbon, cellulose, nitrogen which consider as energy source for maximising microbial activity. The availability of nutrients in soil is of considerable priority to improve microbial populations. This result is consistent with (42) who found increases in microbial activity after application of wheat straw to soil. Microbial activity was significantly changed after soil compaction. Soil compaction reduced microbial activity from 55.67 mg /g in the non compacted soil to 28.67 mg /g in the compacted soil. After applying high pressure on soil, bulk density increased leading to limited soil pores. Soil pores are conditionally important for retaining oxygen, water and organic carbon which support the microbial community (43). Therefore, microbial activity can be immediately affected by limitations of water and oxygen which help for fast-growing community. In addition, the restriction of gas diffusion in soil after compaction may decrease CO_2 emission in the compacted soil. Reduced CO_2 efflux in compacted soil was observed by others (44, 45, 46).

There was an interaction plot **(**$p<0.001$) between treatment and compaction (Figure 1). This can approach that the both factors (treatment and compaction) had a direct effect on microbial activity. Consequently, the application of wheat straw to the compacted soil maximized microbial activity compared to the compacted control treatment. The percentage of rehabilitation of microbial activity in compacted soil was 28% as compared to compacted control treatment. The rehabilitation process of the compacted soil may come from the higher amounts of organic carbon which incorporated with soil after addition of organic residues. The products of microbial decomposition of plant tissue and litters are resistant compounds such as fats, lignin, and waxes (47). These products are responsible for stabilizing soil aggregates and improve soil properties with increasing soil productivity.

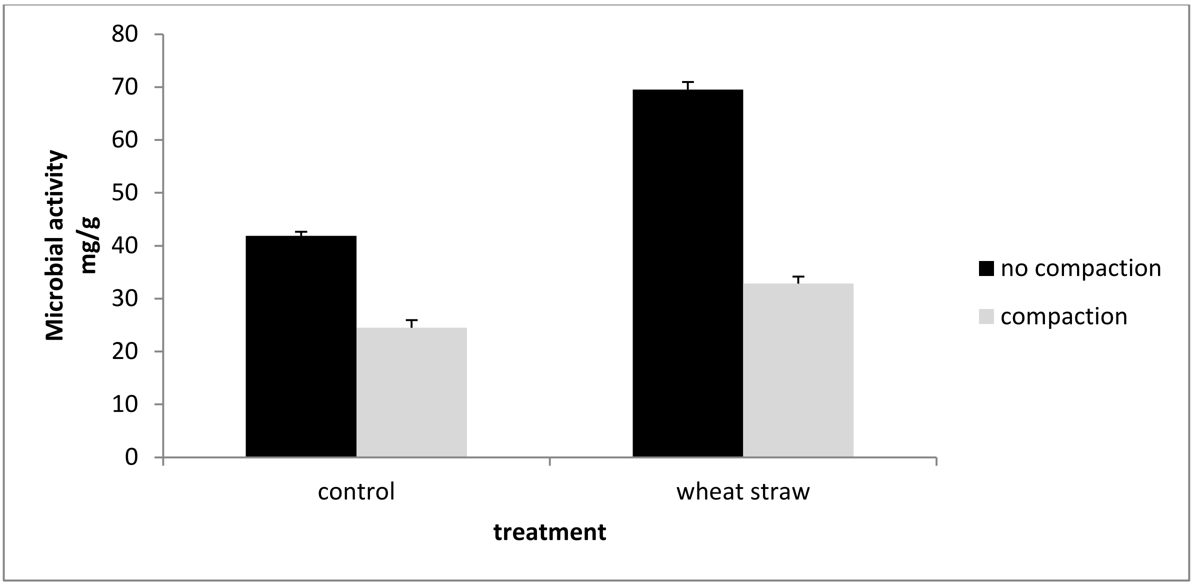

Figure 1. Interaction ($p<0.001$) plot between treatments (control, wheat straw) and compaction for the microbial activity in soil. (Bars represent standard errors) .

2- Effect of compaction and wheat residues on bacterial and fungal abundance

In general, the addition of wheat straw maximised total bacteria and total fungi compared with the control treatment. The increase in total bacteria and total fungi abundance was a result of enhanced microbial development due to the wheat straw, which creates a habitable pool of accessible nutrients to the microorganisms (48). Compaction of soil led to a significant reduction in total bacteria and total fungi in a comparison with non-compacted soil **(**Figure 2, 3). The reason behind that could be attributed to soil compaction which may have restricted the growth of microorganisms as result of increased bulk density, reduced soil macro- porosity (49) and decreased O_2 availability (50, 51). These conditions could lead to limited soil aeration which might therefore inhibit the growth of aerobic microorganisms.

Interactions plots (Figure 2, 3) were found between treatment and compaction indicating that wheat straw and compaction played an important role in changing total bacteria and total fungi in soil. Furthermore, the compacted soils plus organic residues amendment were significantly recovered to a certain level by increasing total bacteria and total fungi compared with the compacted control treatment. In addition, the percentages of rehabilitation of total bacteria and total fungi in the compacted soil plus organic residues were 85 % and 66 % respectively. This result can suggest that bacteria are more withstanding to the condition of compaction than fungi. Bacteria can be anaerobic in soil living without level of O_2. The low level of oxygen following compaction may encourage bacteria to double their numbers in soil. (52) found that denitrifying bacteria were predominant in compacted soil, which increased N_2O emission. The growth of denitrifying bacteria can be higher with large bulk density (1.74) in the absence of oxygen (49).

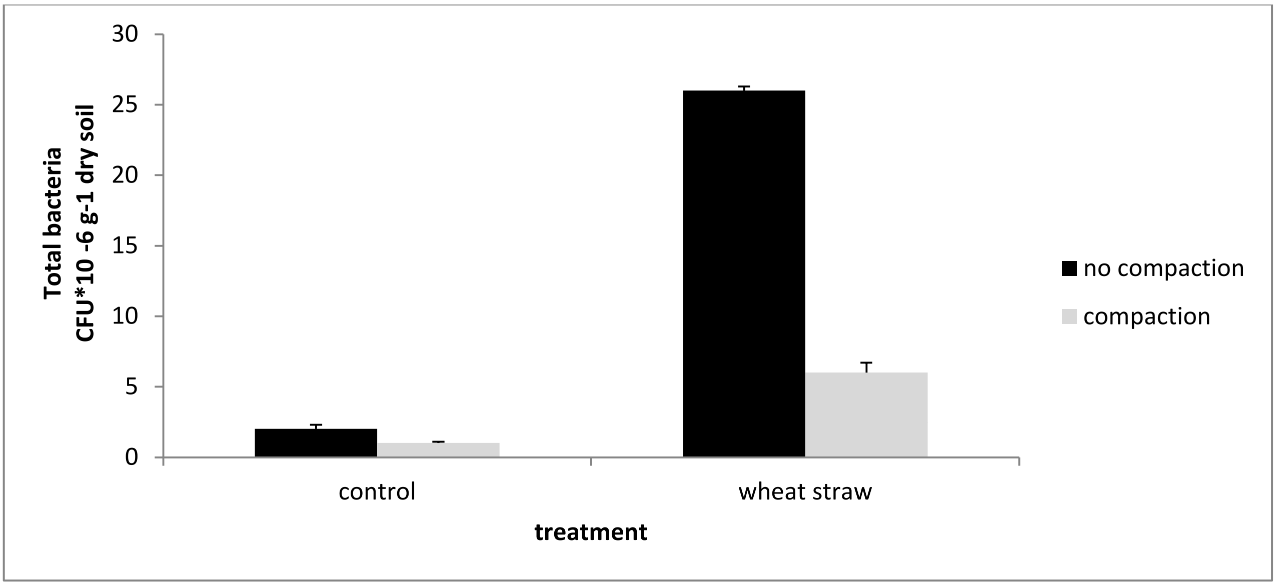

Figure 2. Interaction (p<0.001) plot between treatments (control, wheat straw) and compaction for the total bacteria in soil. (Bars represent standard errors) .

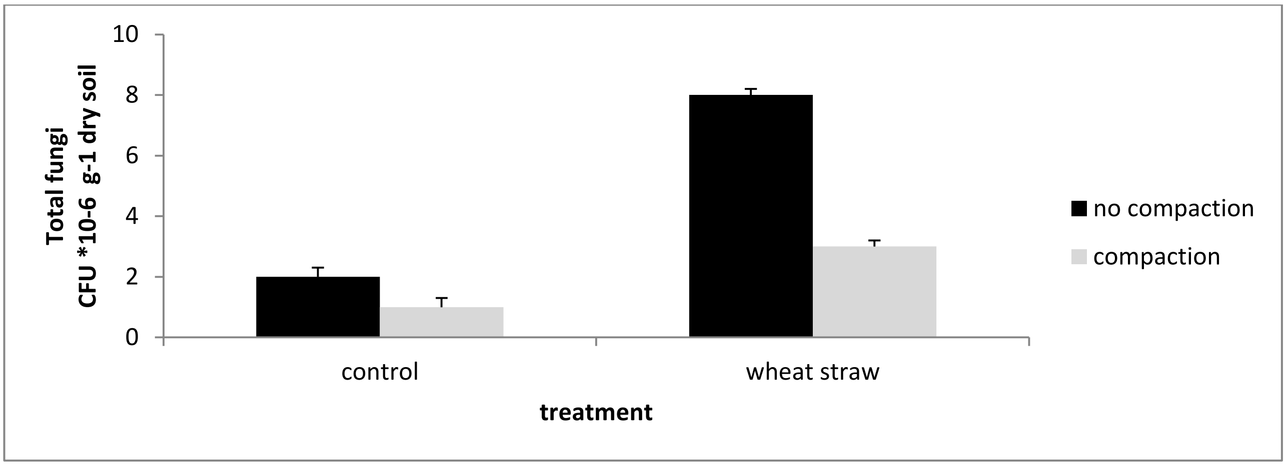

Figure 3. Interaction (p<0.001) plot between treatments (control, wheat straw) and compaction for the total fungi in soil. (Bars represent standard errors) .

3- Effect of compaction and wheat residues on organic carbon and mineralisation process in soil

The application of wheat straw to soil increased significantly the percentage of organic carbon in soil. Decomposition products of litters are fats, lignin, and waxes (47). These products can be responsible for increasing organic carbon content and soil productivity. The decomposition of plant residues can also produce chemical transformations which relate with mineral particles to form stable aggregates. These stable aggregates provides organic matter ''self protection'' from further decomposition (53). There were no significant differences (p value= 0.16) in amount of organic carbon in the compacted and non- compacted soil. An interaction plot (Figure 4) was occurred between treatment and compaction indicating that both factors had a role in quantifying the percentage of organic carbon in soil. This interaction can demonstrate that organic carbon recorded more increases where residues were incorporated in soil without applying compaction whilst there was a slight increase in organic carbon after applying compaction with wheat straw compared with compacted control treatment. The percentage of rehabilitation of the compacted soil was 10% following the addition of wheat straw as compared with compacted control treatment. Large bulk density in soil restricted microbial activity by reducing air availability in soil resulting to a low decomposition process and microbial products. (49) noted that organic carbon content was low in soil with large bulk density due to lower microbial activity. Furthermore, compaction of soil increased the percentage of organic carbon in control treatment. This can be evident that the compaction of soil in control reduced the CO_2 release from soil leading to higher amounts of organic carbon in the compacted soil following two months of incubation.

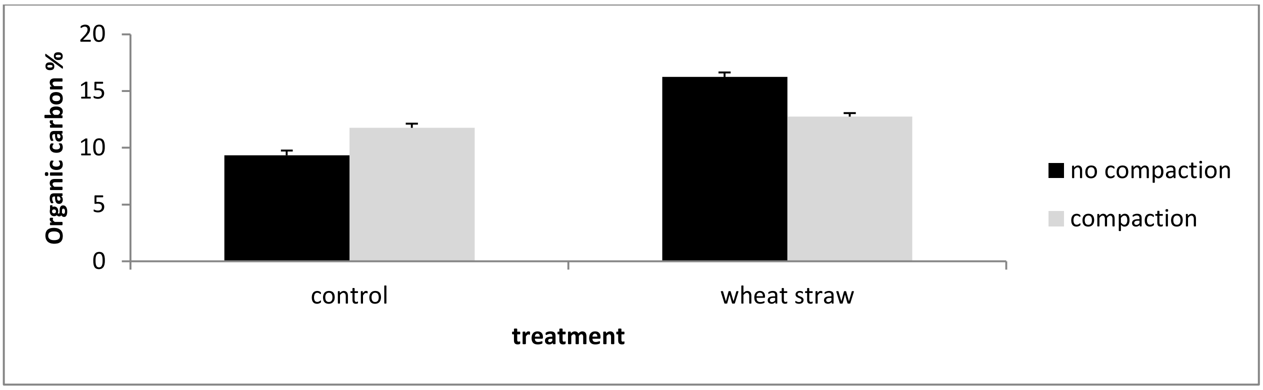

Figure 4. Interaction (p<0.001) plot between treatments (control, wheat straw) and compaction for the organic carbon in soil. (Bars represent standard errors) .

Results proved (Figure 5) that the compaction of soil limited significantly the mineralization process in soil. Compaction of soil increased the bulk density of soil and resulting to lower amounts of oxygen which can affect the life of microbial regime in soil. In this study, microbial activity was decreased by compaction. Microorganisms can participate in the decomposition of organic matter in soil and nutrients cycle. This result in agreement with (54) that studied the influence of soil compaction in a loamy sand soil on C mineralization . They found that the C mineralization rate was strongly depressed at a bulk density of 1.6 Mg m^{-3}, compared with the other treatments. From the interaction plot (Figure 5) can frame that the decomposition of soil was slower in the compacted soil. However, addition of wheat straw increased slightly the mineralisation constant in compacted soil in a comparison with compacted control treatment. This status is highly likely important due to the significant role of organic residues in rehabilitation the compacted soil. The increased percentage of mineralization constant was 20 % in the compacted soil plus organic residues as compared with the compacted control treatment.

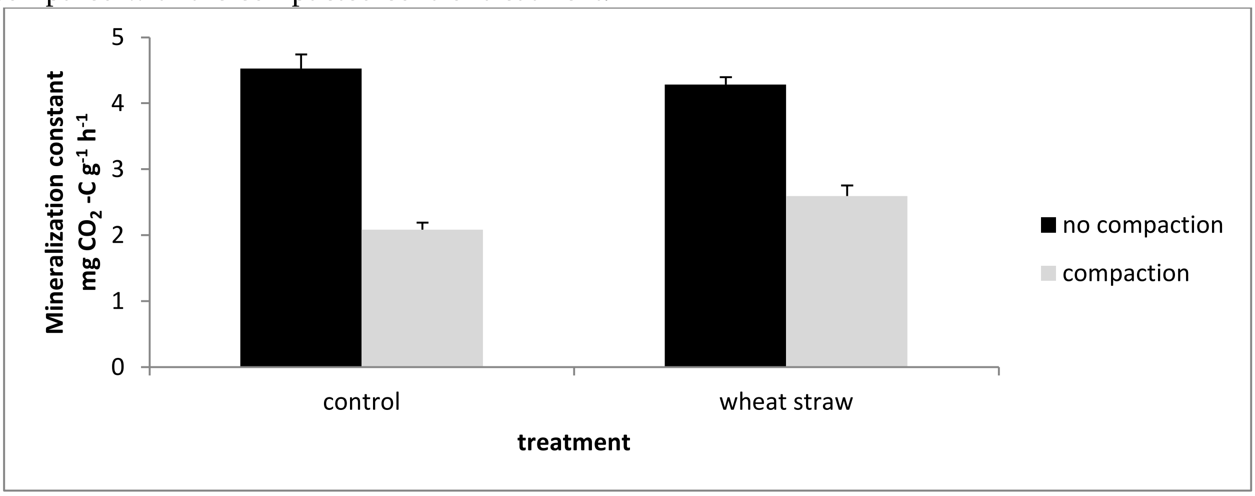

Figure 5. Interaction (p<0.001) plot between treatments (control, wheat straw) and compaction for the mineralization constant in soil. (Bars represent standard errors) .

Conclusion

It can be concluded that microbial activity, total bacteria, total fungi and organic carbon increased significantly after addition of wheat straw. Soil compaction reduced significantly microbial activity, total bacteria, total fungi and the mineralization process. The application of wheat straw to the compacted soil maximized the microbial activity, total bacteria, total fungi and mineralization constant compared to the compacted control treatment. The percentages of rehabilitation of compacted soil were 28%, 85 %, 66 %, 10% and 20 % for microbial activity, total bacteria, total fungi, organic carbon and mineralization constant respectively. This experiment indicated that soil compaction minimised soil microbial community and its impact on soil nutrient cycle. Furthermore, it was found that the response of bacterial community to plant residues in the compacted soil was higher than fungal community indicating that bacterial community is more resistant and resilient to the disturbance of logging in the arid land.

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