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Araştırma Makalesi/*Research Article (Original Paper)*

Investigation of The Effects of Organic Matter Application on Soil Compaction

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Abstract: One of the problems, farmers suffer in recent decade, is soil compaction. Different parameters such as soil texture, moisture, soil organic matter, and machine weight and machine traffic affect soil compaction. These parameters should be managed to prevent soil compaction. In this research, the effects of sheep manure and vermicompost with 0, 2, 4, 6 and 8% levels were investigated on compaction of loam and clay loam soils using standard Proctor test at moisture content under the critical moisture. Tests were arranged as a complete randomized factorial experimental design with three replications. The SPSS.17 software was used for statistical analysis. Results showed that all application levels of both organic matters had significant effects on decrease in soil compaction. Application of 8% organic matter decreased soil compaction by 9.25%. Organic matter application into the soil decreased critical moisture linearly. Organic matter application was more effective on clay loam soil than loam soil, especially at higher levels of 6 and 8%. At lower application levels of 2 and 4%, vermicompost was more effective on soil compaction than manure; however at higher level of 6 and 8 % , manure was more effective in decreasing soil compaction. The lowest bulk density of 1.48 gr cm^{-3} was obtained with adding 8% of organic matter which decreased soil compaction by 10% in comparison with the treatment without organic matter.

Keywords: Manure, Proctor Test, Soil Density, Vermicompost

Eklenen Organik Maddenin Toprak Sıkışmasına Etkilerinin Araştırılması

Son on yılda çiftçilerin yaşadığı sorunlardan biri toprak sıkıştırmasıdır. Toprak dokusu, nem, toprak organik maddesi, makine ağırlığı ve makine trafiği gibi farklı parametreler toprağın sıkışmasını etkiler. Bu parametreler toprağın sıkışmasını önleyecek şekilde yönetilmelidir. Bu araştırmada, kritik nem altında nem içeriğinde standart Proctor testi kullanılarak, tınlı ve kil tın topraklarda sıkışma üzerine 0, 2, 4, 6 ve 8 seviyelerinde koyun gübresi ve vermikompostun etkisi araştırılmıştır. Testler, tam şansa bağlı faktöriyel deneme deseninde 3 tekerürlü olarak düzenlenmiştir. İstatistiksel analiz için SPSS.17 yazılımı kullanılmıştır. Sonuçlar, her iki organik maddenin eklenen seviyelerinin de toprak sıkışmasının azaltılması üzerinde önemli etkileri olduğunu göstermiştir. Organik maddenin %8 uygulamasında, toprak sıkışması % 9.25 oranında azalmıştır. Toprağa organik madde ilavesi, kritik nemi doğrusal olarak azaltmıştır. Organik maddenin %6 ve %8 civarında uygulamalarında, tınlı toprakla karşılaştırıldığında, killi tın toprak üzerinde, daha etkili olmuştur. Toprak sıkışmasının azaltılmasında %2 ve 4 gibi düşük seviyelerde vermikompost, koyun gübresinden daha etkilidir; Bununla birlikte, %6 ve % 8'lik seviyelerde koyun gübresi, daha etkili olmuştur. En az kütle yoğunluğu (1,48 gr/cm^3), organik madde içermeyen işlemlere kıyasla toprak sıkışmasını %10 azaltan %8 oranında organik madde ilavesiyle elde edilmiştir.

Anahtar kelimeler: Gübre, Proctor Testi, Toprak Yoğunluğu, Vermikompost

Introduction

Soil compaction is defined as an increase in the soil bulk density due to an external factor, such as the passing of the tractor, hence it reduces soil ventilation porosity. Soil compaction creates a hard layer in the soil that prevents the penetration of water, air and nutrients into the soil and plant root, and then restricts the root growth and prevents the plant to get required water and nutrients (Ramadhan 2014; Abbaspour-Gilandeh and Sedghi 2015). Therefore, it reduces plant growth and eventually yield. In developed countries with advanced mechanization in agriculture, soil compaction and its effect well-known and statistics of compaction existence was reported in those countries (Gadernazhad et al. 2018). At present, solutions have been presented in those countries, such as traffic control, but are not commonly used. In Iran, soil compaction was not known very well. It may assumed that, since heavy and large agricultural tractors aren't normally used in Iran, the problem of compaction does not seem acute, however it should be noted that in many cases soil compaction exists, but experts relates its effect to other parameters. As the country moves towards advanced mechanization, soil compaction becomes more visible and challenges farmers. So, It should be known and consider the effective factors in its creation and manage that to prevent it. There are many researches that focused on finding soil resistance values that prevent rooting of the plant and its penetration into the soil (Blouin et al. 2008; Miransari et al. 2009; Bayhan et al. 2002).

Taylor et al. (1963) investigated the effects of soil compaction on cotton and forage corn production, it was reported that when the mechanical strength of the soil was higher than 3 MPa, the cotton root could not penetrate into the soil. Growth rates as well as the yield of both products were significantly reduced when the strength of the compacted layer was higher than 2.5 MPa. The yield of cotton and forage corn products in the case of hard pan existance was half of that found in soils with low resistance. According to similar studies, the range of soil mechanical strength that limits root growth is detected between 2-2.5 MPa for different products (Lutz et al. 1986; Sojka et al. 1990; Wells et al. 2001).

In the research conducted at the USDA Agricultural Research Center, root infiltration into the soil was measured in treatments with different densities and compared with the recorded data from a penetrometer. The results showed that root penetration decreases linearly with respect to soil penetration resistance, and when soil resistance increased to 2 MPa the plant roots could not penetrate into the soil. (Ekwue & Stone, 1995). By conducting a series of field experiments, they examined the effect of increasing organic matter on soil density, shear strength and penetration resistance of two soil types of sandy loam and clay in four levels of organic matter (OM) of 0, 4, 8 and 12% in terms of mass rate. The effects of field traffic were evaluated using different blows number of standard proctor test hammer (5, 15 and 20 blows), while all different moisture levels were below the critical value. Soil density, penetration resistance and shear strength increased with increasing moisture content to a critical level and, with increasing moisture content more than critical value, the mentioned indexes were reduced. Adding OM to the soil reduced the soil resistance, shear strength and soil density. With the increment in the percentage of OM, the reduction values in the above indicators were increased. Also, the results showed that the effect of OM on the resistance properties of the soil depends on the level of moisture and the type of organic matter.

Shirani et al. (2010) investigated the effect of soil tillage systems with two cultivating methos of plowing with disk (soil depth of 15 cm) and conventional plowing with moldboard plow (30 cm depth) and 3 levels of cow manure (0, 30 and 60 t/ha) on soil density by measuring the cone index in a corn field. Measurement was performed at 3 times before planting, maximum growth of crop (stage 7 to 9 leaf) and after harvesting (about 7 months after planting). The results showed that at the depths of 0-20 cm, there was no significant difference between two tillage methods, but this difference was significant at depths of 20-40 cm, and the reduction of the cone index with conventional tillage was about 1.5 times of the disk tillage. Addition of manure had a significant effect on soil resistance at depths of 0 to 10 cm. However in the depths more than 10 cm, it was not significant due to high moisture content and soil structure destruction. It was observed that treatments of 30 and 60 t/ ha at planting and maximum growth stages had a significant difference with control treatment without organic matter. In the harvesting stage, cone index measurement showed that only 60 t/ha treatment had a significant difference with control treatment. This indicated that the addition of OM in appropriate rate increased the stability of aggregates compared to the control treatment. Gupta et al. (1987) noted that the addition of low levels of organic matter (about 10 t/ha) to soil had no significant effect on soil compaction after the tractor pass. Barzegar et al. (2000) also, by studying soil resistance by adding 0, 27 and 60 t/ha, concluded that adding 60 t/ha had the greatest effect on soil compaction. Mosaddegi et al. (2000) in a field trials investigated the effect of manure containing 3 levels of 0, 50 and 100 t/ha, up to a depth of 20 cm by disk, was mixed with soil and after 5 months tests were conducted at moisture levels of 0.6 and 0.8 of plastic limit by a 2-wheel drive U650 model tractor in two pass. Bulk density (BD) and cone index (CI) up to 40 cm depth were measured as compaction indexes. The results of analysis of variance showed that the effect of moisture and farmyard manure and number of tractor passes on soil BD and CI was significant at $p<1\%$, but the effect of the tractor pass number was significant at $p<5\%$. The mutual effect of moisture and manure on BD was significant at $p<1\%$ and also mutual effect of moisture and the number of passes on BD was significant at $p<1\%$, indicating different soil behavior at different levels of moisture and number of passes. The mutual effect of manure rate and the pass number on BD was significant at $p<5\%$ indicates that the manure has a different effect on the soil compaction in the second pass in comparison to the first pass.

Increasing moisture caused an increase in the effect and depth of soil compaction, because with increasing moisture up to PL the orientation of the soil particles under pressure was quick due to the presence of water molecules and this resulted in a sharp increase in soil BD. Increasing OM caused significant decrease in BD in all moisture contents. With increasing the rate of added manure, especially in high moisture content, the magnitude of BD decrement was high, in other words, OM reduced soil compaction. In treatments containing manure, the surface soil exhibits less resistance to germination. The depth of the compaction was about 35 cm in control treatment while it was 25 cm as manure was added to the soil (ΔBD> 0.05 Mg/cm^3). Increasing manure reduced the BD at moisture contents clos to PL in second pass of the tractor, indicating that OM acts as a cushion and prevents the transfer of stress to the soil (Mosaddeghi et al. 2000).

According to previous studies, the objective was to investigate the effect of adding organic matter on soil compaction and its control, hence the effects of sheep manure as conventional fertilizer and vermicompost as a new fertilizer on reducing soil compaction in different soil textures by standard compaction test were investigated.

Material and Methods

In this research, two different soils; loam texture common in Ardabil fields and clay loam texture common in Ardabil Agriculture Research Center lands, were provided for tests. Hydrometer method (Bouyoucos, 1962) was used to determine the texture class of the soil samples at the laboratory (Table 1).

Table 1. The texture of tested soils

Soil texture	clay	silt	sand	Organic matter%	Liquid limit Moisture, %	Plastic limit moisture, %
Loam	25.01	29.23	45.66	1.03	46.32	23.27
Clay loam	32	28	40	1.01	42.35	19.34

In different situations, an experiment was conducted to determine the moisture content of the soil sample. Therefore, after weighing the wet soil, the specimen was placed in an oven for 24 hours at 105°C. Dry specimen weight was determined and then the moisture content based on dry base was determined.

A standard Proctor method was used to conduct the tests. The mould, upper ring and hammer are seen in Fig 1. The mould, has a depth of 115 mm and a diameter of 100 mm and its volume is equal to 903.32 cm^3. The upper moving ring, has a depth of 62.5 mm and a diameter of 100 mm. The diameter of hammer is 50 mm and its weight is 2.5 kg. The falling height of the hammer to the collision point was 30.5 cm. First of all the weight of the mould together with bottom plate was recorded.

Figure 1. Bottom mould, upper ring and hammer.

About 3 kg of sieved soil from 4.76 mm opening size was prepared and, based on the desired OM percentage, the required OM was added to the soil (Fig. 2). For example, for 2%, 60 g of manure was added to the 3 kg soil and mixed completely by hand. To start the density test, the moisture content of the mixture should be increased to 8%. On the basis of Eq. 1 the moisture content of the mixture was determined and the determined amount of water was calculated and sprayed to the soil-manure mixture during mix operation.

$$\Delta w = G\,(Wf - Wi) / (100 - Wf) \qquad (1)$$

In which:
Wf = final desired moisture content, gr
Wi = initial moisture content of the mixture, gr
G = weight of soil-organic matter mixture, gr
ΔW = amount of required water must be added to the mixture, gr

By spraying the required water calculated by Eq.1, the sample is well mixed to allow the moisture to be uniformly spread. Then, the mixture was released for about 2 hours to absorb the moisture. The movable upper ring was fixed on the mould and a layer of 5 to 8 cm was formed in the mould. The soil was pressed tidily by hand to flat its top surface. Then, the soil layer was compacted with 25 uniform hammer blows. The second and third layers of the soil were created in the same manner, each was compacted with 25 hammer blows. After removing the upper ring, the upper surface of the soil inside the mould was cut and flattened with a special metal ruler. Then mould together with dense soil inside it was weighed and recorded. By weighing the weight of the empty mould, the wet weight of the dense damp soil was computed, and also the density of the damp soil was calculated by dividing the mass of dense soil to the mould volume. The dry soil dry mass was calculated from Eq. 2.

$$\gamma_d = \gamma_w / (1 + w\%) \qquad (2)$$

Where:
γ_d = mass of dry soil, gr/cm^3
γ_w = mass for wet soil, gr/cm^3
W% = percentage of soil moisture,%

Figure 2. Prepared Soil and manure mixture which left 2 hours and ready for test.

In the next step, the dense soil inside the mould was removed with a special jack, and a sample of about 60 gr was removed and weighed to determine the moisture content. The removed soil from the mould was fragmented with a special metal ruler and mixed with the soil in the plate (Fig. 3)

Figure 3. Bringing soil sample out of the mould and its mix with the soil in the plate.

The weight of the soil in the pan was determined by weighing, and by spraying the water computed by Eq.1 the moisture content increased by 3% to reach about 11%. All steps of creating 3 layers and hammer blows and determining the wet and dry density of the soil was repeated with 11% moisture. In subsequent stages, moisture content was increased by 3% and in each step the soil density was determined. At a stage of the test, it was found that with increasing moisture content, the wet density was decreased compared to the previous stage. At this stage, the experiment ended. According to Fig. 4, which shows the variation in the dry density versus to the moisture content of the soil, at moisture content of 20.7% with the maximum density of 1.628 gr/cm^3 was obtained, and with increasing moisture content up to 24% the dry density was decreased by 1.52%.

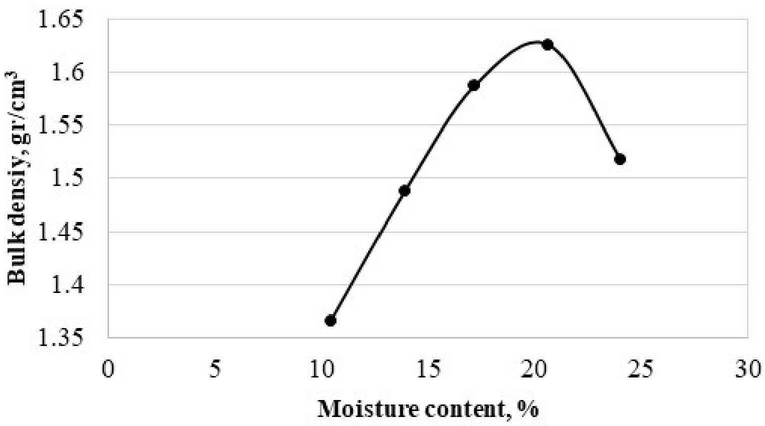

Figure 4. The variation of soil dry density versus soil moisture content (loam soil with 2% of vermicompost).

Density test was performed for all treatments in 3 replications and the critical moisture content was determined in which the highest dry density was obtained. Thus, the effect of soil type, OM type and its percentage on the magnitude of maximum dry density changes was determined.

According to the research objectives, the statistical design was carried out as a factorial experiment in a completely randomized design. The parameters studied were soil texture (loam and clay loam), organic matter (sheep manure and vermicompost) and organic matter content at 5 levels of 0, 2, 4, 6 and 8%.

To predict and express the effect of the soil type and manure type and its incorporated value on soil bulk density obtained data were analyzed by means of SPSS 17 software.

Results and Discussion

Analysis of variance showed that the effects of all three main parameters such as soil type, organic matter (OM) type and OM percentage, and the binary and triple effects of these parameters on soil density were significant at P<1% (Table 2).

Table 2. Variance analysis of the effect of soil type, organic matter type and its percentage on soil compaction

Factor	DOF	Sum of square	Mean square	F value
Soil type	1	0.001	0.001	276.28**
OM type	1	0.001	0.001	29.92**
OM percentage	4	0.129	0.32	1197**
Soil type ×OM type	1	0.0001	0.0001	4.034**
Soil type×OM percentage	4	0.002	0.001	19.15**
OM type×OM percentage	4	0.005	0.001	44.14**
Soil type×OM type×OM percentage	4	0.003	0.001	31.03**
Error	40	0.001	0.000027	
Total	60	150.36		

**=statistically significant (p<1%)

Analysis of variance showed that all levels of both OMs had a significant effect on reducing density in comparison with control treatment, and the amount of soil density decreased linearly by increasing the percentage of added OM (Fig. 5). There was also a significant difference between the different percentages of added OM. By adding 8% of vermicompost and sheep manure, the bulk density of dense soil reduced from maximum value of 1.662 gr/cm^3 to 1.509 and 1.506 gr/cm^3, respectively. Therefore, the effect of these two types of OM on the soil density reduction was about 9.25%. In general, adding OM increases soil resistance against to the compaction (Agili et al, 2011). The following are as the most common reasons for justifying the effect of OM on increasing soil resistance to the compaction: strengthening of internal and external soil aggregates (strengthening soil cohesion), increasing soil elasticity, reducing bulk density due to the mixing of OM with the soil matrix, a localized change in the electric charge of the soil particles, change in the friction angle of the soil, and the softening effect in the soil. Depending on the OM type and its distribution in the soil, each of the above mechanisms has a different contribution to the effectiveness of OM on decreasing soil compaction (SÖane, 1990). Agili et al. (2011) reported that the soil bulk density decreased linearly with the increment of OM into the soil.

The highest bulk density 1.49 gr/cm3 was obtained in chemical fertilizer treatment at moisture content of 20.9% and the least value 1.09 gr/cm3 in compost treatment with a concentration of 100 tons per hectare in moisture of 17.1%. They attributed the decrement of the bulk density with the increasing of OM to agglomerate and increasing the soil elasticity. Mosaddegi et al (1999) showed that the addition of 50 and 100 t/ ha of manure reduced bulk density significantly in comparison to the control without manure. Also, there was a significant difference between 50 and 100 t/ha effect on soil density. They recommended 50 t/ha in terms of its effect and economy.

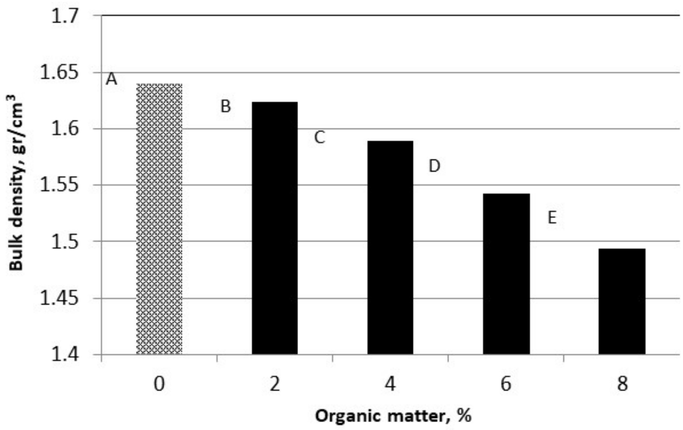

Figure 5. The effect of OM percentage on the soil bulk density.

Figure 6 shows the effect of added OM rate on decreasing the soil bulk density. Regarding the reduction slope, it is clear that in high percentages, the effect of OM on reducing the bulk density was greater than lower values. Therefore, by adding 50 t/ha, which is about 2 percent by weight, the effect of the OM on reducing the density was less than that of 100 t/ha (4% by weight). Although adding 6 and 8% of OM is much more effective than 2 and 4 percent in reducing the density, it is not economical for farmers to add such amounts of OM.

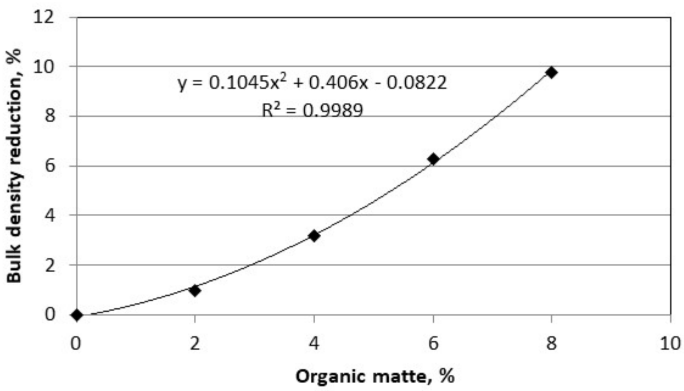

Figure 6. Relationship between added OM percentages on reduction of soil bulk density.

Also, by adding OM, the critical moisture content (the moisture content in which the soil gained the highest density) increased linearly. Figure 7 shows the effect of adding vermicompost on increment of critical moisture value. The maximum critical moisture without adding OM was 18.9%, and adding 8% of vermicompost increased critical moisture to 23%. An increase of 8% vermicompost causes a 27.7% increase in the critical moisture content of the soil. In control treatment at moisture around 18.9%, agricultural activities are not possible and, if conduced, will cause the soil to be damaged and degraded, while adding 8% of OM at that moisture agricultural operations can be accomplished without soil degradation. Shirani et al. (2010) showed that the addition of organic material to the soil increased the suitable moisture range for agricultural operations, and, generally, soil compaction significantly decreased with the addition of OM. This effect, especially in heavy soils (clay), where agricultural operations are difficult at high moistures, improves reduction of soil compaction.

Mosaddegi et al. (2000) found that in control treatment, the suitable moisture content for machine traffic was 0.6 of plastic limit, while adding OM increased that to 0.8 of plastic limit. Their study showed that adding farmayard manure of 50 t/ha caused a significant reduction in the soil density and increased critical soil moisture content.
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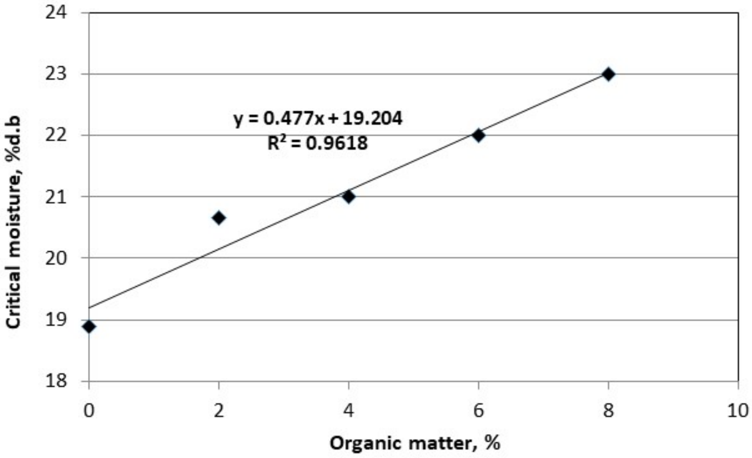

Figure 7. The effect of different percentages of Vermivompost on critical moisture in Loam soil.

Binary effect of soil type and organic matter on soil compaction

Figure 8 shows that, in both loam and clay loamy textures, soil compaction decreased with increasing OM content. In control treatment, heavy clay loam gained the highest bulk density 1.652 gr/cm^3 and bulk density was 1.629 gr/cm^3 in loam soil. In clay loam soil, increasing the rate of addded OM showed a greater effect on the reduction of density. Adding 4% of OM in both soil types the bulk density was the same, while at rates of 6 and 8% the bulk density of clay loam soil was less than loam type (Fig. 8). An increase of 8% of OM showed reduction of 7.7% and 9.5% in loam and clay loam soils, respectively.

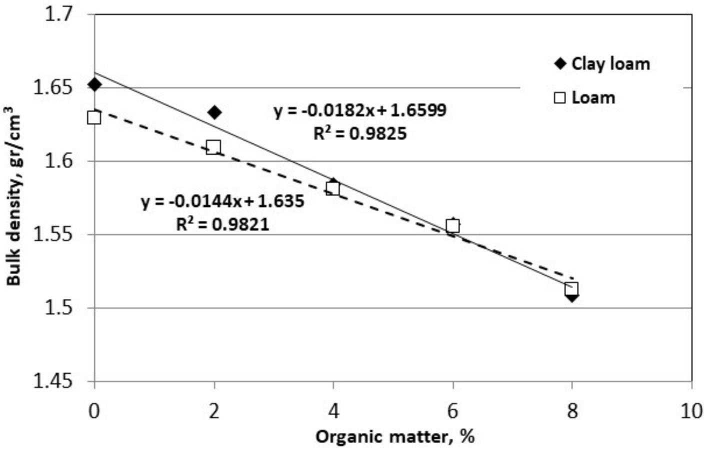

Figure 8. The effect of added OM on bulk density in both soil types of loam and cay loam.

Effect of organic matter and organic matter content on soil density

For each type of OM the soil compaction decreased with increasing adding rate (Fig. 9). However their effects were different, in lower percentages of 2% and 4% vermicompost was more effective than sheep manure in reducing the soil density. In higher rates of 6 and 8%, sheep manure was more effective than vermicompost. The slope of bulk density reduction for sheep manure has been uniform in all rates. Vermicompost had a different process and there was no significant difference between 4% and 6%. The results of the study (Agili et al., 2011) showed no specific trend for the effect of fertilizer type and its percentage.

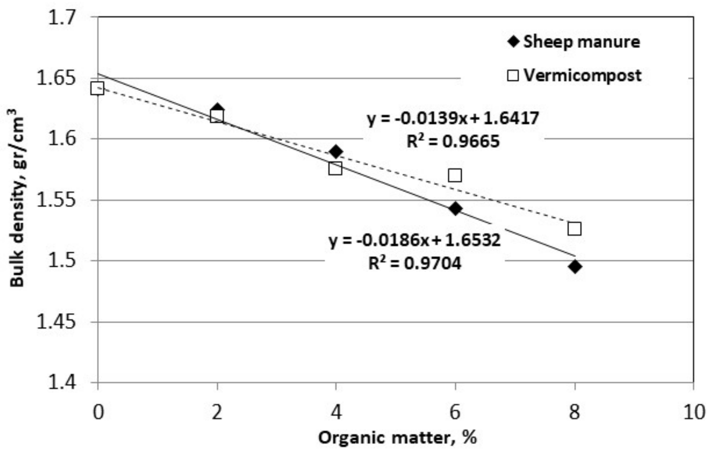

Figure 9. Effect of OM type and its added rate on soil compaction.

For both types of soil texture, sheep manure was more effective than vermicompost in reducing the soil bulk density (Fig. 10). Also, the density in loam soils was less than clay loam soil. The least bulk density of 1.57 gr/cm^3 obtained for loam soil by adding sheep manure and the highest value of 1.59 gr/cm3 was for clay loamy soil by adding vermicompost. Aghili et al. (2011) showed that adding 50 and 100 t/ha of cow manure was more effective than compost and sludge in reduction soil compaction and resistance.

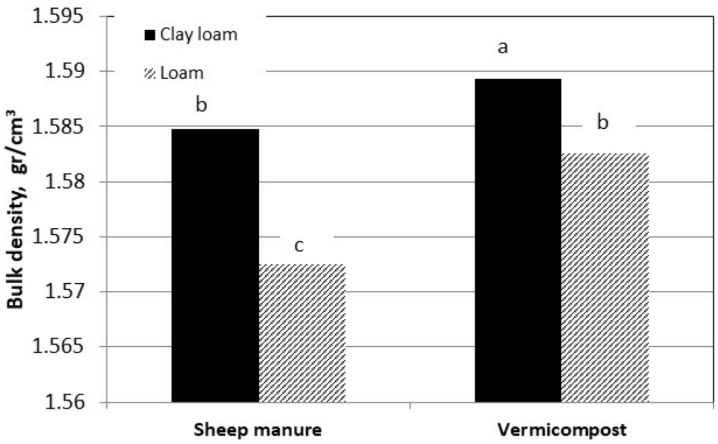

Figure 10. Binary effect of OM type and soil texture on soil bulk density.

As the analysis of variance (Table 3) shows, the mean difference for interation all three factors examined for bulk density. The least value of 1.48 gr/cm^3 was obtained at loam soil containing 8% of sheep manure, which reduced the density by 10% compared to control treatment. Adding 8% of sheep manure to clay loam soil also reduced the bulk density to 1.5 gr/cm^3 a reduction of 9.5% compared with control treatment. Adding vermicompost in rate of 8% decreased bulk density 9.5% and 8% in clay loam and loam soil. Hence it was concluded that vermicompost was more effective in clay loam than loam soil in terms of reducing compaction.

Table 3. Triplet effect of soil type, OM type and OM rate on soil compaction

OM type	OM percentage, %	Clay loam	Loam
Sheep manure	0	1.652^{a}	1.629^{c}
	2	1.64^{b}	1.608^{d}
	4	1.578^{ef}	1.591^{e}
	6	1.55^{j}	1.55^{i}
	8	1.506^{k}	1.483^{l}
Vermicompost	0	1.652^{a}	1.629^{c}
	2	1.626^{c}	1.609^{d}
	4	1.581^{f}	1.57^{g}
	6	1.577f^{g}	1.56^{b}
	8	1.509^{k}	1.542^{ij}

Conclusions

1- Results showed that all levels of both organic matters effects were significant on decreasing bulk density in comparison with non-organic matter treatment. By increasing the percentage of added organic matter the value of soil density decreased linearly. There was also a significant difference between the different added OM percentages. By adding 8% of vermicompost and sheep manure, the bulk density of dense soil was decreased from 1.662 gr/cm^3 to 1.509 and 1.506 gr/cm^3, respectively. Therefore, the effect of these two types of organic matters on reduction on bulk density was 9.25%. In general, organic matter reduces the risk of soil compaction

2- For both types of organic matter with increasing their rates the soil bulk density decreased. However their effect was different. In low percentages of 2 and 4% vermicompost was more effective than manure in reducing the density. However, in higher percentages of 6 and 8%, sheep manure was more effective than vermicompost. Indicates that vermicompost absorbed soil moisture faster than sheep manure hence it was more effective at low percentages. But at high rates sheep manure enhanced soil elasticity more than vermicompoct and this property was dominant factor in decrement soil compaction. The slope of bulk density for manure was uniform in all percentages. Vermicompost had a different effect and there was no significant difference between 4% and 6%.

3- In the absence of organic matter, heavy clay loam had the highest bulk density of 1.652 gr/cm^{-3}, in this case, the bulk density of loam soil was 1.629. In clay loam soil, increasing the percentage of organic matter had a greater effect on the reduction of density, at 4% of the organic matter the bulk density for both types of soil textures was approximately the same, and in rates of 6 and 8, the bulk density of clay loam soil was less than the loam texture. This shows that OM was more effective on fine soils such as clay loam and clay than medium soils like loam and silt loam. It was the effect of the value of clay percentage which increased the influence of OM matter.

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