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COMPARATIVE ANALYSIS OF THE EFFECTS OF MANURE AND VERMICOMPOST ON THE ELASTICITY MODULUS OF LOAM SOIL IN DIFFERENT MOISTURES

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This study aims to investigate the effects of manure and vermicompost in terms of soil elasticity modulus changes in loam soil. The uniaxial compression test measures the compressive strength of a soil cylinder without any lateral load. The modulus of elasticity was determined by plotting the strain-stress diagrams and calculating the slope of these diagrams. The increase in moisture and organic matter content significantly improved soil flexibility and decreased its elasticity modulus. It was found that adding animal manure had a greater effect on the flexibility of the soil as compared to vermicompost, while the elasticity modulus of the samples containing animal manure was lower. The interaction effect of moisture and the organic matter content indicated that the increase in humidity was more effective in the soil containing vermicompost as compared to the soil containing manure, such that when the manure rate was around 19%, the moisture increase had no significant impact on the elasticity modulus. It was found that adding organic matter was more effective at the low moisture level of 15.5% than at higher moistures where the effect of adding organic matter did not affect the soil elasticity modulus decrement as strongly.

Keywords: soli fexiblity; soil compaction; organic matter; uniaxial test

Agricultural machines, wheeling across farmland, and ploughing at a constant depth gradually cause soil compaction and create a hardpan, which limits the growth of plant roots and reduces crop yields (Majchrzak et al., 2017; Abbaspour-Gilandeh and Abbaspour-Gilandeh, 2019; Moinfar et al., 2022). According to research, a conical index of 2–2.5 MPa was determined as the critical limit of soil compaction for root growth and penetration in the soil (Keller et al., 2013). To remove this hardpan created in the subsoil to the detriment of root growth and proper soil drainage, deep ploughing is required. This, however, is a high energy endeavour and a considerable cost for farmers (Barik et al., 2014).

Tillage is one of the most basic stages in the production of agricultural products. It requires a lot of energy for cutting, lifting, turning, reducing the size of soil clods, and restructuring the soil. Under these conditions, the friction created between the tilling tool and the soil may account for more than 30% of the total draft force (Manuwa, 2012).

Unlike sustainable land management, land use intensification has a negative impact on both soil health and quality (Triantafyllidis et al., 2020). Achieving sustainable agriculture is not possible without sustainable soil which, in turn, is not possible without soil organic matter. And the amount of the latter depends on the organic matter addition rate and proper soil management. Soil organic matter is considered as an effective factor in soil formation and evolution. The energy from the breakdown of this resource meets the needs of many microorganisms such as bacteria, fungi, and actinomycetes.

High amounts of animal manure and other plant residues are produced annually. If they are not properly utilised, huge amounts of waste material are created and can cause environmental pollution, while with proper usage, manure can play a constructive role and provide a very valuable and low-cost resource to increase soil fertility for crop production. Animal manure, widely used as fertiliser in crop and soil structure improvement, also increases moisture absorption and storage capacity in the soil (Rehman et al., 2023). Organic fertilisers have the ability to balance the undesirable properties of sandy and clay soils. In light- and even medium-textured soils, nutrients are easily washed away and removed out of the reach of crop roots. Adding organic matter to such soils causes adhesion of fine soil particles and formation of coarse aggregates. These aggregates are water resistant and, by creating large pores, increase water conductivity and soil aeration which are necessary for plant and microorganism growth.

The main problems of clay soils are compaction and reduced permeability, both of which can be mitigated by adding organic matter. It has a positive effect on the physical, chemical, biological properties and fertility of soil, and is known as one of the more influential factors determining the stability of soil grains and soil structure such that they prevent the destruction of soil surface due to collision of rain drops and runoff.

The fibrous and humic materials in organic matter increase the cohesion of aggregates and improve soil stability (Malkawi et al., 1999). Ohu et al. (1989) reported bulk density reduction and increased water retention capacity after adding of any kind of organic matter. Boyle et al. (1989) reported that the addition of organic matter resulted in an increase of soil porosity in soils treated with organic materials. Rücknagel et al. (2007) considered the low stability of aggregates as a characteristic of soils in arid and semi-arid areas and stated that the addition of organic matter to the soils in such areas would improve the conditions to form proper aggregates.

By adding 0, 40, and 80 tons of farm fertiliser per year for three years and applying field traffic with a contact pressure of about 250 kPa, Söane (1990) concluded that the cone index in fertilised treatments was much lower than the control treatment.

Ekwue and Stone's (1995) compaction analysis studied the effects of added organic matter on the density, shear strength, and penetration resistance of sandy loam and clay soils at four levels of organic matter (OM) content of 0, 4, 8, and 12% by mass. The effects of traffic were evaluated by applying a varying number of blows with a standard proctor test hammer (5, 15, and 20 blows), while all the different moisture levels were below the critical value. Soil density, penetration resistance, and shear strength increased with increasing moisture content up to a certain critical level, after which they started to drop. Furthermore, the results showed that the extent of the OM effect on the resistance properties of soil depended on the level of moisture and the type of organic matter. Gupta et al. (1987) suggested that the addition of low amounts of organic matter (about 10 tons per hectare) to the soil did not significantly affect soil compatibility or reduce the shear strength of soil that was under compaction due to tractor tires wheeling.

Shirani et al. (2010) investigated the effectiveness of soil tillage systems utilising two cultivating methods of ploughing with disk (soil depth of 15 cm) and conventional ploughing with mouldboard plough (30 cm depth) as well as 3 levels of cow manure fertilisation (0, 30, and 60 $t \cdot ha^{-1}$) on soil density by measuring the cone index in a corn field. The measurement was performed 3 times: before planting, at the maximum crop growth (stage 7 to 9 leaf), and after the harvest. It was found that at the depths of 0–20 cm, there was no significant difference between the two tillage methods, but this difference was significant at the depths of 20–40 cm. The reduction of cone index with conventional tillage was about 1.5 times that recorded for disk tillage. It was observed that the treatments of 30 and 60 $t \cdot ha^{-1}$ at the planting and maximum growth stages made a significant difference as compared to the control treatment without organic matter. At the harvest stage, the cone index measurement showed that only the 60 $t \cdot ha^{-1}$ treatment made a significant difference relative to the control treatment. This indicated that the addition of OM in appropriate amounts increased the stability of aggregates as compared to the control treatment.

As follows from the literature review, no such research on elasticity modulus of agricultural soils has been conducted to date. This may be due to the fact that in past research, this mechanical property of the soil was not considered important enough. However, in fully mechanised agriculture, soil compaction has become one of the important challenges in farming, one that is directly dependent on soil elasticity. For that reason, in modern finite element and discrete element methods of soil simulation, one of the main factors that needs to be input into the software is the soil elasticity modulus. Given the above, the aim of this study is to investigate and compare the effect of manure and vermicompost fertilisation on the modulus of soil elasticity in loam soil with varying moisture content.

Material and methods

The modulus of soil elasticity is one of the significant engineering characteristics of agricultural soil. To study the effects of manure and vermicompost on the modulus of elasticity of loam soil, experiments were conducted at 5 organic matter levels of 2, 5.2, 8.7, 13.6, and 19% and four different moisture levels of 15.5, 18.8, 22.4, and 24.2%, in triplicate. Data analysis was conducted in the factorial format as a completely randomised design using the SPSS21 software. In total, 135 tests were performed to determine the modulus of soil elasticity using a compression uniaxial test apparatus. Soil texture was determined using the hydrometric test to identify the amount of sand, silt, and clay in the soil sample. The percentages of sand, silt, and clay were 35, 39, and 26, respectively, and soil texture was loam. To determine soil moisture, wet soil samples were weighted, after which they were placed in an oven at 105 °C for 24 hours and weighed again to determine the weight of the dry sample. The percentage dry basis moisture content was calculated with the ASTM method (ASTM D2216-19, 2019).

The uniaxial compression test measures the compressive strength of a soil cylinder without any lateral load. This test is similar to the unconsolidated and undrained three-axial test. By testing a material in compression, compressive strength, yield strength, ultimate strength, elastic limit, and elastic modulus can be determined. The length to diameter ratio (L/D) of the soil sample should be between 2 and 2.5 (ASTM D2166-16, 2016), and the measurement accuracy should be 0.01 inch. A sample with the length of 4.5 inches (11.43 cm) and a diameter of 2 inches (5.08 cm) can be used. The L/D ratio of the sample should be such that the failure planes do not intersect at a 45° angle relative to each other, and the sample length should prevent it from buckling.

The standard automatic uniaxial device method was used to perform the unconfined compression test. The mould and the compaction hammer are shown in Fig. 1. The main mould, also called the lower mould, was 112 mm in length and 50 mm in diameter, with a volume of 306 mm^3. The mould consisted of two parts that had been bolted together. The soil sample could be easily removed from the mould by separating these parts. The upper mould, called the moving ring, was 3 cm in depth and 5 cm in diameter. The hammer had a cross-section of 5 cm and weighed 2.12 kg. The falling height of the hammer from the top to the bottom was 22.7 cm.

Fig. 1 The mould and the compaction hammer

Vermicompost and cow manure were used as additional organic fertilisers. Approximately 450 g of soil was prepared from a sieve no. 4 (4.76 mm). Based on the target weight percentage, the desired amount of organic fertiliser was added to the soil. For instance, to achieve 2% content, 9 g of OM matter was added to the soil and mixed thoroughly by hand. To start the compaction test, the moisture of the mixture was raised to 8%. The mixture moisture and the amount of water needed to reach the target moisture of 8% were determined in accordance with ASTM D2216-19 (2019).

The two parts of the mould were fastened together, and the moving ring was attached to the main mould and filled with the prepared mixture in three steps. At each step, one third of the mixture was placed inside the mould and compacted with 10 blows of hammer. In order for the hammer fall height to remain consistent for all blows, it was pulled up all the way and then released (Fig. 2). The second layer and then the third layer of soil were placed into the mould in the same manner and each layer was compacted by 10 blows of the hammer. The top mould was removed, and the soil top surface was completely flattened using a special metal ruler. The two parts of the mould body were separated so that the soil sample remained on the top of the bottom plate. Once the mould was removed, the soil sample was placed between the loading plates (Fig. 3).

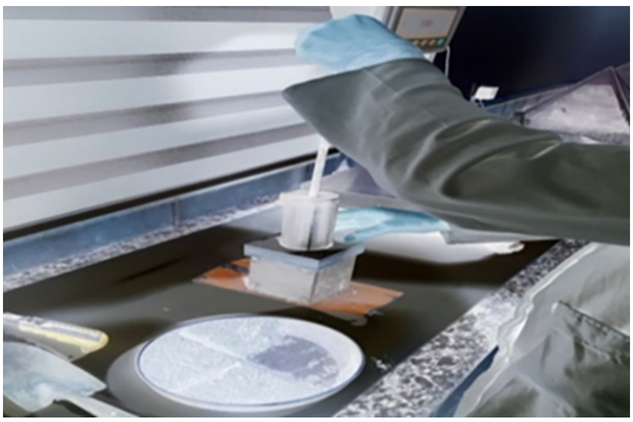

Fig. 2 Preparation of the soil sample inside the mould and its compaction with the hammer

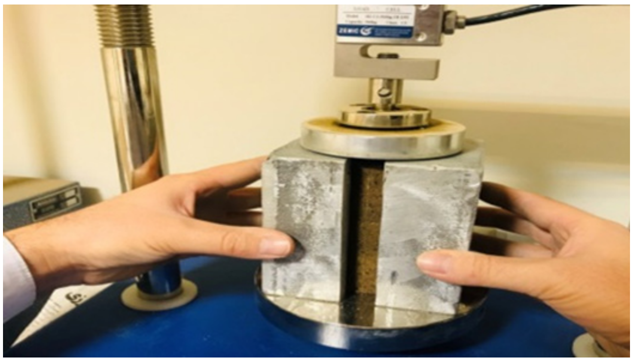

Fig. 3 Taking the sample out of the mould and putting it under the load

To determine the modulus of soil elasticity, the cylinder-shaped samples of soil were placed between loading plates of the test device (Fig. 4). The top movable plate was in contact with the load cell to record the compressive force on the soil. The movable plate started to move with a standard constant speed, and the compressive force on the soil sample and its vertical displacement were recorded as a stress and strain diagram displayed simultaneously on the device screen.

The movement of the moving plate of the device continued until the sample stress reached the yield point and the diagram reached a declining trend (Fig. 5). Once

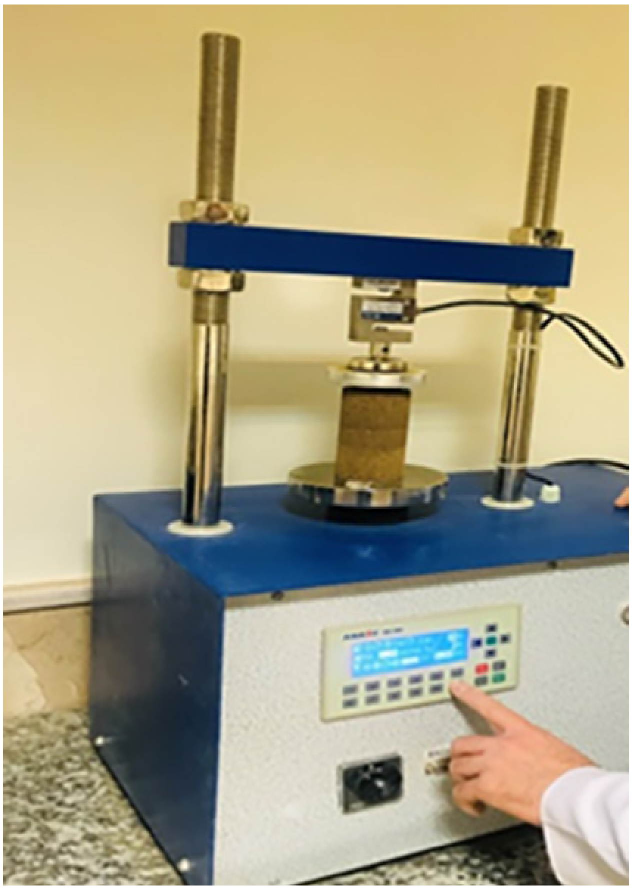

Fig. 4 Unconfined compression test conducted with the uniaxial device

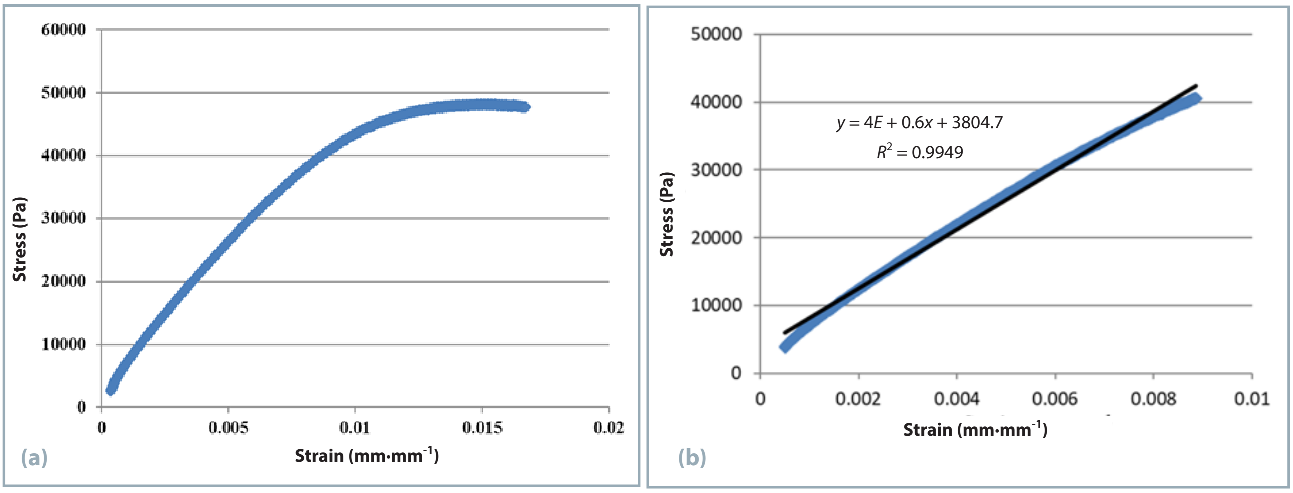

Fig. 5 The stress-strain diagram obtained experimentally (a), and the data trend line in the elastic zone (b)

collected, the force and displacement data were transferred to Excel and by plotting the strain-stress diagram and with calculating the slope of the straight part of the curve to the yield point, the modulus of soil elasticity was calculated (Fig. 5).

Results and discussion

The results of the analysis of variance of the data obtained from measuring the modulus of soil elasticity are shown in Table 1. The coefficient of variance (CV) was 0.79%.

It was found that moisture, organic matter type, and the percentage of organic matter had a significant effect on the soil elasticity modulus change at the probability level of 1%. Also, the dual interactions of the OM type * M, OM type * OM, and M * OM were significant at the probability level of 1%. Finally, the triple interaction effect of OM type * M* OM on the modulus of soil elasticity was significant at the probability level of 1%.

Table 1 Variance analysis of data from the measurement of soil elasticity modulus

Treatment	DOF	SS	MS	F
OM type	1	38858456	38858456	4663**
Moisture (M)	3	12927163	4309054	517**
Organic matter (OM)	4	24770874	6192719	743**
Iteration	2	227	113	0.01
OM type * M	3	697960	232653	28**
OM type * OM	4	416876	104219	12.5**
M * OM	12	1080060	90005	10.8**
OM type * M * OM	12	1183051	98588	11.8**
Error	78	649960	833	
Total	119	80584267		

DOF – degree of freedom; SS – sum of squares; MS – mean of square; F – Fisher's *F* test value

The effect of organic matter type on the modulus of soil elasticity

Figure 6 shows that the animal manure had a more significant positive effect on soil flexibility than vermicompost. The modulus of elasticity was 1353.21 Pa in the soil containing manure as compared to 2491.2 Pa for the soil treated with vermicompost. This can be related to the fact the elasticity of cow manure was overall higher than that of vermicompost. Adding manure to the soil improved its flexibility more than vermicompost, and the soil reacted like cushion under compressive force.

In countries where farmlands contain less OM, farmers typically add manure as fertiliser to facilitate the appropriate growth of agricultural crops. As follows from the analysis, another beneficial effect of manure is increased soil flexibility which helps to control soil compaction (Shahgholi and Janatkhah, 2018).

The effect of organic matter amount on soil elasticity modulus

According to Fig. 7, it is clear that increasing the amount of organic matter added to the soil decreased the modulus of soil elasticity linearly, making it more flexible and lighter. The determination coefficient of 0.986 showed a direct

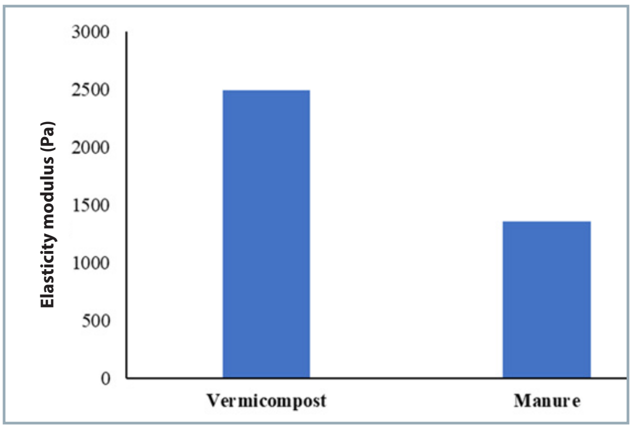

Fig. 6 Comparison of the effects of organic matter type on soil elasticity modulus

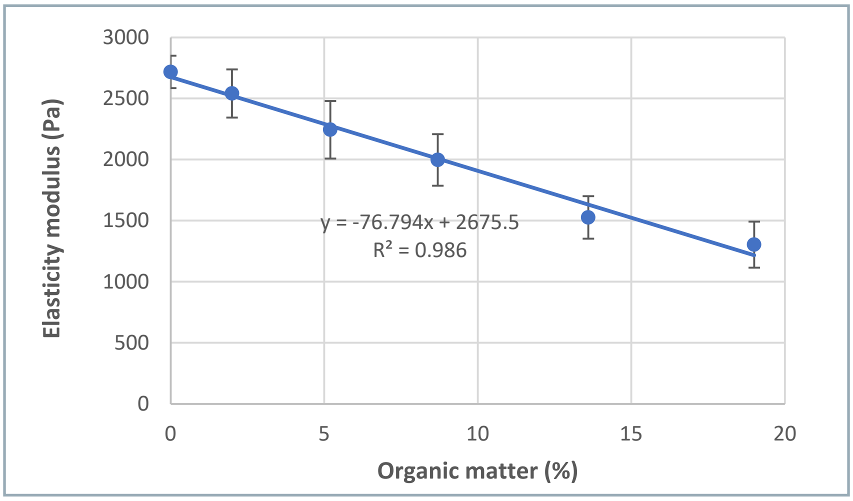

Fig. 7 Changes in the modulus of elasticity with the increasing addition of organic matter (error bars represent ±1 standard error of the mean value)

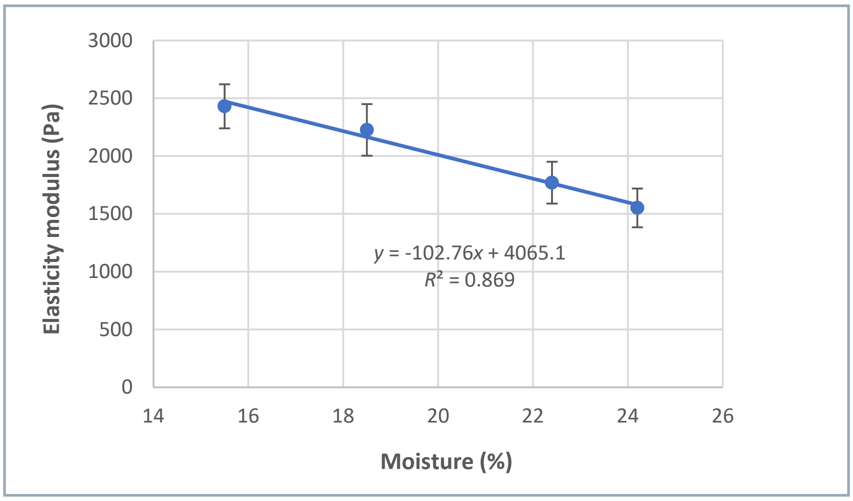

Fig. 8 Comparison of the effects of soil moisture content on the modulus of soil elasticity (error bars represent ±1 standard error of the mean value)

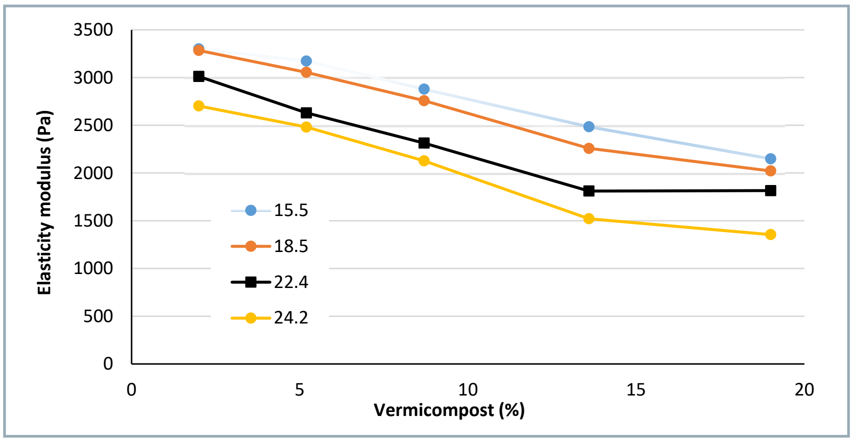

Fig. 9 Mutual effect of vermicompost and soil moisture content on soil elasticity modulus

relationship between increased OM content and decreased elasticity. This stems from the fact that the texture of organic matters was finer and more flexible as compared to agricultural soil particles. Consequently, the addition of these materials into the soil resulted in a reduction of the modulus of soil elasticity. Similar positive effects of organic matter on the improvement of soil mechanical properties have been reported by some researchers (Ekwue and Stone, 1995; Davies, 1985; Gantzer et al., 1987). As follows from the diagram, with the increasing the amount of the organic additive, the modulus of elasticity decreased linearly.

The effect of moisture on soil elasticity modulus

Figure 8 shows that increasing soil moisture content caused a linear reduction in the modulus of soil elasticity; it decreased from 2327 Pa for the moisture content of 15.5% to 1504 Pa for the moisture content of 24.2%. Notably, this decrease was steeper within the moisture content range of 18.5–22.4%. The phenomenon can be related to the rapprochement to critical moisture. It has been reported that the modulus of soil elasticity decreases with increasing soil moisture and the trend can be attributed to higher adhesion of moist soil as well as its increasingly non-solid phase (Ekwue and Stone, 1995).

Figure 9 shows the mutual effect of OM increments at different moisture levels on soil elasticity modulus. Elasticity modulus was declining with increasing OM percentage. The diagrams also show elasticity decreasing with the incremental increase of soil moisture. The slope of the elasticity change diagram was linear for the vermicompost percentages of 2 up to 13.6%, but between 13.6 and 19%, the slope of the curves was moderated at the higher moisture range of 22.4–24.2%, indicating that further increase in vermicompost content would no longer reduce the modulus of elasticity. This indicates that at high moisture content nearing the critical moisture level at which the soil becomes highly vulnerable to compaction, the addition of vermicompost beyond the optimal value of 15% does not have a significant

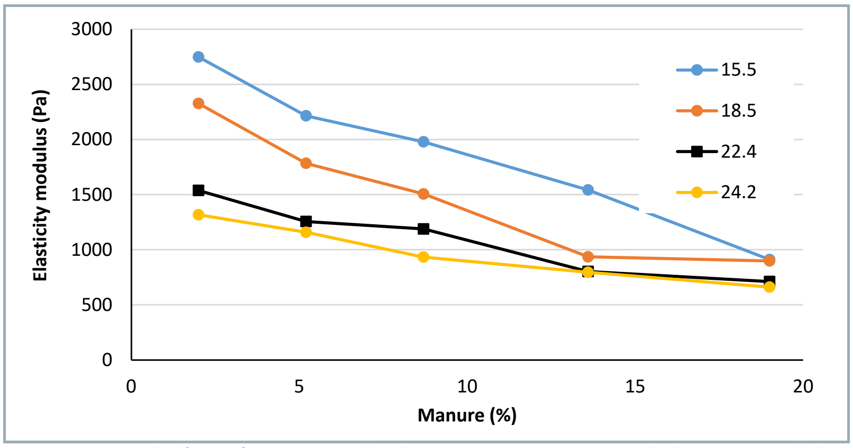

Fig. 10 Mutual effect of manure and soil moisture content on soil elasticity modulus

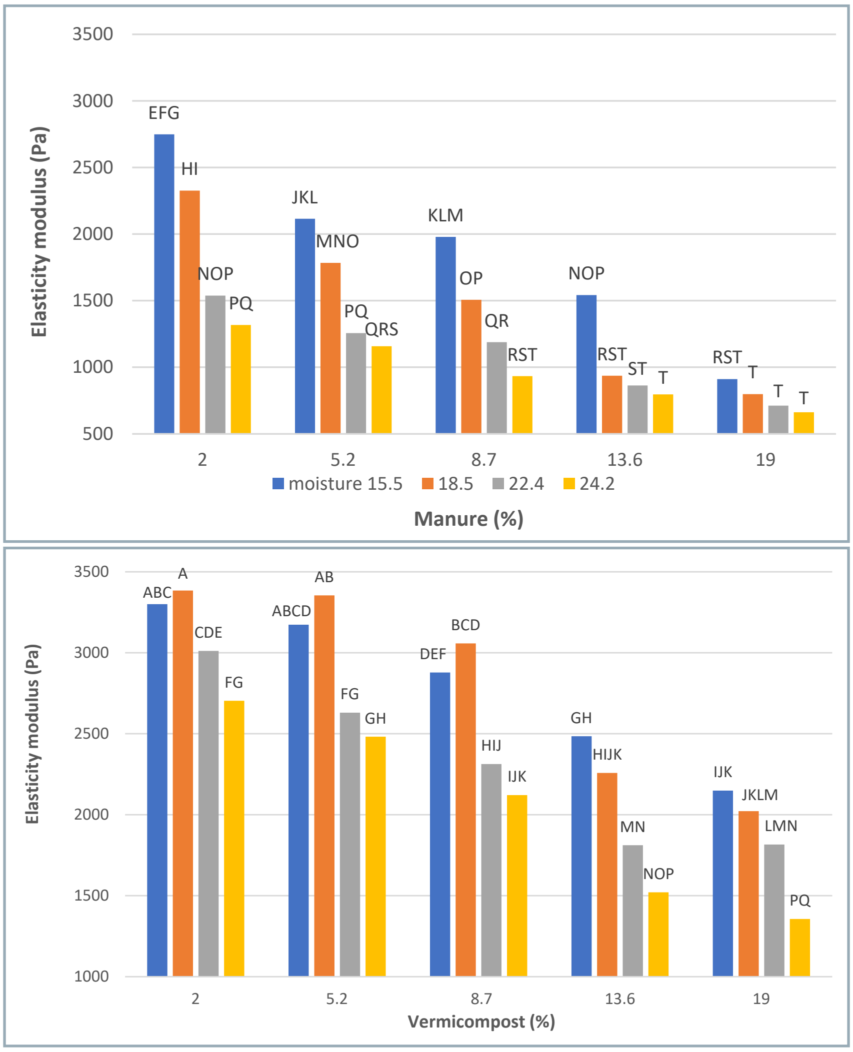

Fig. 11 Comparison of the triple interaction effect of OM type, OM addition percentage, and moisture content on soil elasticity modulus (manure – top, vermicompost – bottom)

effect on reducing the modulus of elasticity. Another noteworthy point is the negligible difference between the two curves registered for the 15.5% and 18.5% moisture content levels, and the significant drop in the modulus of elasticity values as moisture content increased from 22.4 to 24.2%. This difference in behaviour can be related to the fact that the moisture content values of 22.42 and 24.2% are close to the critical moisture level of soil samples (Davies, 1985; Mosaddeghi et al., 2000) and, as already mentioned above, at critical moisture content, any pressure results in high strain on the soil.

Figure 10 shows that as the moisture content increased, the slope of the elasticity modulus decrement curves decreased. This indicates that at low moisture levels, adding manure was more effective in decreasing elasticity modulus than at higher moisture content. The important point was that for the manure content of 19%, there was not significant difference with regard to moisture content in terms of effects on soil elasticity modulus. This confirms the conclusion that in soil containing high percentage of organic matter, the effect of moisture content on elasticity modulus was low. This is a very promising observation as it shows that despite farmers' lesser control over the moisture level while conducting agricultural operations, soil compaction can still be avoided. As such, ensuring high content of organic matter will allow farmers to perform agricultural operations in a wide range of moisture levels, including at relatively high soil moisture. However, at the low OM content of 2%, the impact of moisture content (M) on elasticity modulus was very high and decreased only as more OM was added.

The results of comparing the average triple interaction effect of OM type, OM addition percentage, and moisture (M) on the modulus of soil elasticity for vermicompost and manure are presented in Fig. 11. By comparing the diagrams plotted for manure and vermicompost it was possible to identify clear differences between the two types of fertilisers. For manure, regardless of additive percentage, the modulus of elasticity decreased more sharply with increasing moisture, as compared to vermicompost. Also, changing the percentage of animal manure had a more significant effect in terms of reducing the modulus of elasticity than in the case of vermicompost. The noteworthy point in comparing these two graphs is that for vermicompost at low additive levels, the modulus of elasticity at 18.5% moisture was higher than the corresponding value at 15.5% moisture.

A statistical step-by-step regression model for predicting elasticity modules (E) was developed. The correlation coefficient (R = 0.926) and determination coefficient (R^2 = 0.857) were calculated. The closer these values are to 1, the more the model expresses the relationship between the dependent and independent variables. In other words, the regression model is able to cover a greater percentage of changes in soil elasticity. Based on these coefficients, we can display the regression model as follows.

$$E = 4474.73 - 105.96\ \mathrm{OM} - 91.69\ \mathrm{M} \tag{1}$$

Using this relationship, it is possible to estimate the soil elasticity value.

Conclusion

1. It was found that adding organic matter to loam soil makes the soil more flexible and reduces the modulus of elasticity as compared to natural soil. The comparison of two types of organic matter (vermicompost and manure) showed that manure has a greater influence on improving soil flexibility and decrement of elasticity modulus than vermicompost.
2. It was concluded that soil elasticity modulus can be greatly reduced by increasing moisture. The interaction between moisture and organic matter content indicated that in the case of vermicompost, an increase in moisture showed a greater effect on elasticity modulus decrease when compared to increase in organic matter content.
3. The examination of the interaction effect of moisture and the organic matter content of manure showed that increasing manure content had a greater effect on reducing elasticity modulus than increasing moisture. When organic matter content exceeded 20%, changes in moisture content had practically no effect in terms of decreasing the modulus of elasticity.

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