Eurasian Journal of Soil Science 2021, 10(3), 215 - 221

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Effects of vermicompost applications on Atterberg Limits and workability of soils under different soil moisture contents

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Article Info

Received : 21.09.2020
Accepted : 20.02.2021
Available online : 01.03.2021

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Abstract

The present research was conducted to assess the effects of vermicompost (VC) treatments under different soil moisture contents on consistency limits of sandy-clay-loam (SCL) soils in which lettuce (*Lactuca sativa* var. *crispa*) was cultivated in a greenhouse. Liquid limit (LL), plastic limit (PL), plasticity index (PI), consistency index (Ic) and clay activity (A) values were investigated. Three different VC doses (0, 2.5 and 5% w/w) were applied at 3 different soil moisture contents (100% FC-field capacity, 50% FC and 25% FC). Experiments were conducted in 3 replications over 27 experimental plots (3×3x3). Increasing LL and PL values were observed with increasing VC doses. The greatest LL (46.6%) and PL (37.7%) values were obtained from the 5% VC treatment under high soil moisture content (100%FC) and the lowest LL (35.0%) and PL (23.0%) were obtained from the control treatment under low soil moisture content (25%FC). LL had significant correlations with VC (0.848**), PL (0.904**), PI (0.565**), Ic (0.668**) and A (0.548**). Ic had significant correlations with VC (0.815**), PL (0.417*) and PI (0.740**). As compared to the control treatments, Ic values increased by 13.0% and 21.9% respectively with 2.5% and 5% VC treatments. Ic values were greater than 0.75. Therefore, it was observed that the sandy-clay-loam soils could be cultivated without any structural deformations at FC or higher moisture contents with vermicompost application. Moisture content upper limits for optimal tillage without any structural destructions were suggested as 26.8%, 34.9% and 36.9% for 0%VC, 2.5%VC and 5%VC treatments, respectively. Present findings indicated that VC treatments extended the range of moisture for workability.

Keywords: Atterberg Limits, vermicompost, soil water regimes, soil cultivation, sandy-clay-loam soil.

Introduction

Vermicompost offers a bio-oxidative process through the epigeic earthworms and various microorganisms for stabilization and biodegradation of organic materials (Kızılkaya and Hepşen Türkay, 2014; Ceyhan et al., 2015; Mupambwa and Mnkeni, 2018; Kızılkaya et al., 2021). Inorganic fertilizers have several negative impacts on soil quality and they are also costly practices. Therefore, growers are always searching for compatible and affordable organic sources to improve soil fertility and the other quality parameters. Vermicompost (VC) emerges right at this point as a reliable alternative of inorganic fertilizers (Kizilkaya et al., 2012; Arancon et al., 2008). Vermicompost improves soil microbial activity, aeration and water holding capacity, thus offers an excellent soil amendment (Orozco et al., 1996). Previous researchers reported several positive effects of vermicompost on soil quality parameters (Aksakal et al., 2016; Demir, 2019; Demir, 2020). Soil organic matter (OM) influences both surface area and porosity; however, the water held at greater suctions increases more because an increment in the surface area is expected as an immediate

: https://doi.org/10.18393/ejss.888643
: http://ejss.fesss.org/10.18393/ejss.888643

Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

influence of the OM treatments. The effects of soil OM on soil physical characteristics include increased water holding capacity, decreased bulk density and promoted structural development (Paradelo et al., 2009).

Atterberg limits describe consistency of soils based on soil moisture contents (Terzaghi et al., 1996). Therefore, they are usually referred as consistency limits (liquid limit, LL; plastic limit, PL; plasticity index, PI = LL -PL). Consistency limits were used to assess soil workability for various practices such as cultivation, tillage, harvest and etc. (de Jong et al., 1990). They are also commonly used in soil classification for engineering purposes. Besides, Atterberg limits provide information for interpreting several soil physical and mechanical characteristics such as bearing capacity, shear strength, shrink-swell potential, compressibility and specific surface (McBride, 2008). They are especially used in soil mechanics and geotechnical engineering. Plasticity largely depends on specific surface area of soil particles, thus on clay content and soil particle size distribution (de Jong et al., 1990; Seybold et al., 2008). Soil plasticity is also influenced by exchangeable cations of the soils (Schjonning, 1991) and clay mineralogy (Cerato, 2001). Furthermore, OM content was reported to effect soil plasticity. OM plays significant roles in agricultural lands (Dexter et al., 2008). The present research was conducted to investigate the effects of different vermicompost treatments under different soil moisture levels on consistency limits (LL, PL and PI), consistency index and clay activity of sandy-clay-loam (SCL) soils in which lettuce (*Lactuca sativa* var. *crispa*) was grown in a greenhouse.

Material and Methods

Experimental treatments

Experiments were conducted in greenhouses of Soil, Fertilizer and Water Resources Central Research Institute in Ankara between 24 March and 10 July of 2017. Indoor air temperature was set at 24/20 °C (day/night) and relative humidity was set at 50-55%. Experiments were conducted with 3 different vermicompost (VC) treatments (0, 2.5 and 5% VC (w/w:VC/soil) treatments applied at 3 different soil moisture levels (100, 50 and 25% of field capacity, FC). There were 9 treatments (3×3) in 3 replications. Lettuce (*Lactuca sativa* var. *crispa*) seedlings were transplanted into 7 L plastic pots filled with soil plus VC at specified doses. Following the transplantation, seedlings were irrigated to 100% of FC. Soil moisture was monitored for 2 weeks. Experimental pots were weighed to get the amount of irrigation water to be applied under each soil moisture regime (100%FC, 50%FC, 25%FC). Following the harvest, soil samples were taken for mechanical analyses.

Soil analyses

Hydrometer method was used to get soil particle size distribution (Demiralay, 1993). Field capacity (FC) was determined with the aid a pressure plate (Hillel, 1982). Soil pH values were measured with a pH meter and electrical conductivity (EC) values were measured with an EC-meter (Kacar, 1994). Scheibler calcimeter was used to determine soil lime contents (Soil Survey Staff, 1993). Soil organic matter (OM) was determined with the use of Modified Walkley-Black method (Kacar, 1994). Consistency limits (LL, PL and PI) were analyzed in accordance with the principles specified in Demiralay (1993). PI was calculated as the difference between LL and PL (PI = LL – PL) and Consistency index (Ic) was calculated as Ic = (LL-FC) / PI. Clay activity (A) was determined as A = PI / (% clay) (Baumgartl, 2002). Experimental soils were sandy-clay-loam (SCL) (sand: 56.8%, silt: 18.5%, clay: 24.7%) in texture, slightly alkaline (pH=7.75) with insufficient OM and medium $CaCO_3$ (5–15%) contents and none saline according to EC (1.59 dS m^{-1}) (Soil Survey Field and Laboratory Methods Manual, 2014). General properties of vermicompost are provided in Table 1.

Table 1. Analysis results of vermicompost

pH	EC, dS m^{-1}	OM, %	Total N, %	P_2O_5, kg da^{-1}	K_2O, kg da^{-1}	Ca, ppm	Mg, ppm	Fe, ppm	Mn, ppm	Zn, ppm
7.1	6.5	65.5	2.2	7.3	12.8	25.1	6.6	2.1	271.9	216.0

Statistical analyses

Experimental data were subjected to analysis of variance with the use of SPSS 16.0 software. Duncan's multiple range test was employed to compare significant means at P≤0.01 significance level. Correlations between soil characteristics were assessed through Pearson's correlation coefficients.

Results and Discussion

The effects of vermicompost (VC) treatment on liquid limit and plastic limit under three different soil moisture regimes are presented in Figure 1A and B. The effects of VC treatments on LL and PL were found to be significant (p<0.01) (Table 2). Such effects of VC on LL and PL increased with increasing treatment doses. The greatest LL (46.6%) and PL (37.7%) values were obtained from the 5% VC treatment under high soil moisture content (100%FC) and the lowest LL (35.0%) and PL (23.0%) were obtained from the control treatment under low soil moisture content (25%FC). Increasing LL and PL values were observed with increasing VC doses. LL and PL values might be associated with the change in OM content due to vermicompost applications. VC treatments improve soil OM contents and thus increase water holding capacity, then increase soil moisture-dependent parameters like LL and PL (Bhushan and Sharma, 2002). Aksakal et al. (2016) also reported increasing soil OM contents with VC treatments. Demir (2019) reported that VC applications under 3 different soil moisture contents significantly increased the soil OM content of the soils. Gülser and Candemir (2004) indicated that organic waste incorporation into soils increased LL and PL of the soils. Demiralay and Güresinli (1979) classified soil based on liquid limit as low plastic for LL of <30%, medium plastic for LL of between 30-50% and highly plastic for LL of >50%. Present LL values varied between 35.0 - 46.6%, thus, present soils were classified as medium plastic. LL and PL limit values vary with the clay content of the soils, clay type, OM content and the type of exchangeable cations. Increasing LL and PL limit values were reported with increasing OM and clay content (Baumgartl, 2002; Gülser and Candemir, 2004; Aksakal et al., 2013). As compared to the control, LL values increased with 5% VC treatments by about 19.1%, 22.5% and 32.4% for low (25%FC), medium (50%FC) and high (100%FC) soil moisture contents, respectively. The increase in PL with 5% VC treatments was respectively calculated as 17.4%, 15.9% and 40.4% for low (25%FC), medium (50%FC) and high (100%FC) soil moisture contents. Demir (2019) reported that VC treatments increased soil moisture content at FC. Such an increase than increased soil consistency limits (LL and PL). It was indicated by Hemmat et al. (2010) that increasing specific surface areas also increased soil LL and PL values.

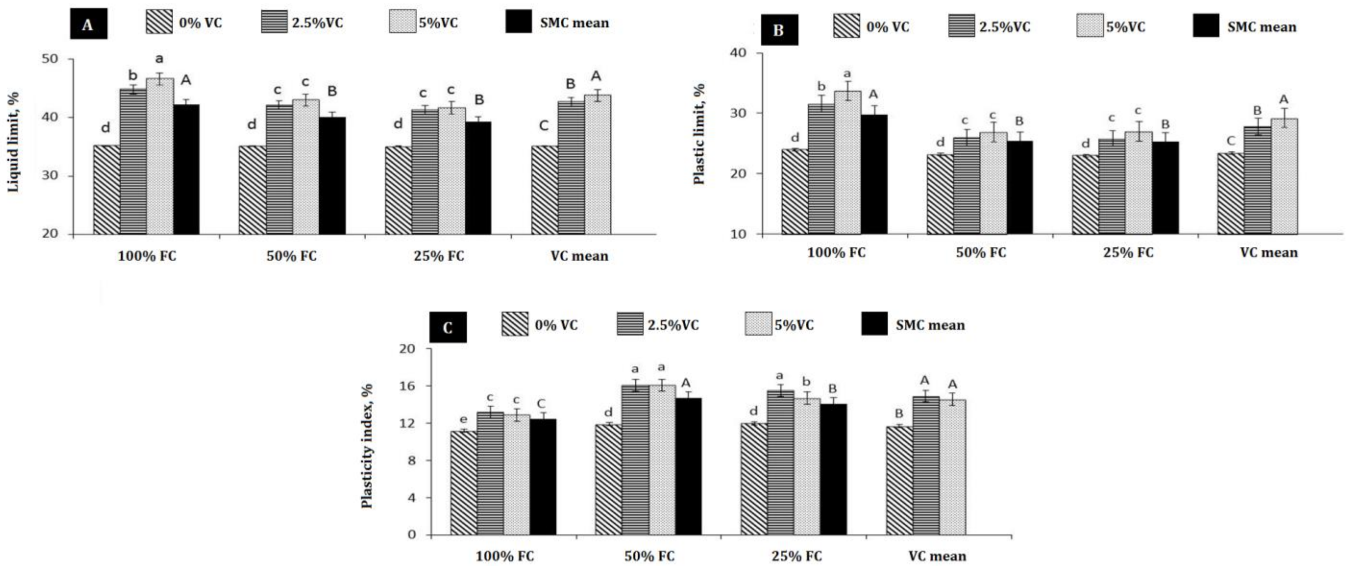

Figure 1. Effects of VC applications under different soil moisture contents on liquid limit (A), plastic limit (B) and plasticity index (C). VC: vermicompost, SMC: soil moisture content, FC: field capacity

Table 2. Descriptive statistics for the soil characteristics

	Minimum	Maximum	Mean	Std. Deviation	CV, %
LL	33.76	47.31	40.53	4.26	10.5
PL	22.19	34.74	26.80	3.56	13.3
PI	11.16	16.30	13.74	1.84	13.4
Ic	0.75	1.04	0.90	0.09	10.0
A	0.45	0.70	0.57	0.08	14.0

LL: liquid limit, PL: plastic limit, PI: plasticity index, Ic: consistency index, A: activity of clays

The highest PI value (16.1%) was observed in 2.5% VC treatment under medium soil moisture content (50%FC) and the lowest PI value (11.2%) was obtained from the control treatment under the high soil water content (100%FC) (Figure 1C). It was observed that 5% VC treatments increased PL and reduced PI, thus improved workability of the soils without any structural destructions. The PI designates the workable moisture range of the soils without generating compaction problems. Soils with greater PI values are more susceptible to compaction (Aksakal et al., 2013). LL also plays an important role in PI value. Jumikis (1984) classified soils based on PI values as: low plastic for PI of <7; medium plastic for PI values of between 7-17; high plastic for PI values of >17. According to this classification, present soils with PI values of between 11.2-16.1 were classified as medium plastic, thus considered to be less susceptible to compaction.

Activity (A) of clays is largely designated by dominant clay mineral of the soils (Campbell, 1991). Baumgartl (2002) classified soils based on A values as: active soils (smectite) for A values of >1.25; normal soils (illite) for A values of between 0.75-1.25; inactive soils (kaolinite) for A values of <0.75). Clay activity values of present soils varied between 0.46 and 0.69 which were less than 0.75 (Figure 2B). Thus, present soils were classified as inactive soils dominated by kaolinite clay mineral with slight swell-shrink potential.

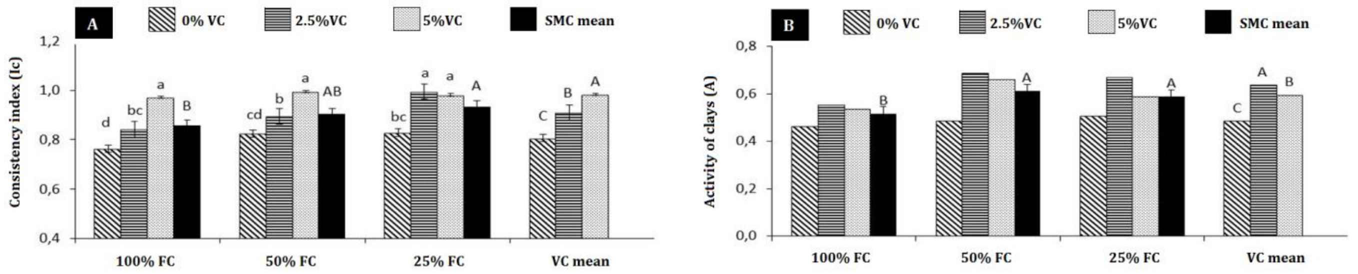

Figure 2. Effects of VC applications under different soil moisture contents on consistency index (A) and activity of clays (B). VC: vermicompost, SMC: soil moisture content, FC: field capacity

Pearson correlation coefficients between parameters are presented in Table 3. LL had significant positive correlations with VC (0.848**), PL (0.904**), PI (0.565**), Ic (0.668**) and A (0.548**). Ic had significant positive correlations with VC (0.815**), PL (0.417*) and PI (0.740**). Sarı et al. (2017) reported that VC had significant positive correlations with LL and PL of different textured soils. Archer (1969) reported highly positive correlations between soil OM and PL of silty-loam soils. Similar correlations among the soil characteristics were also reported by Gülser et al. (2008, 2009), Gülser and Candemir (2004, 2006) and Aksakal et al. (2013).

Table 3. Pearson correlation coefficients between soil parameters

	VC	Clay	Silt	Sand	LL	PL	PI	Ic
Clay	-							
Silt	-	-0.774**						
Sand	-	0.129	-0.727**					
LL	0.848**	-0.009	-0.066	0.113				
PL	0.678**	0.010	-0.047	0.063	0.904**			
PI	0.650**	-0.040	-0.062	0.140	0.565**	0.159		
Ic	0.815**	0.155	-0.185	0.121	0.668**	0.417*	0.740**	
A	0.556**	-0.066	-0.076	0.191	0.548**	0.158	0.960**	0.737**

** significant at 1% level, * significant at 5% level, VC: vermicompost, LL: liquid limit, PL: plastic limit, PI: plasticity index, Ic: consistency index, A: activity of clays

Soil moisture ranges for workability of the soils

VC treatments increased Ic values as compared to the control (Figure 2A). The greatest Ic (0.99) was observed in 5% VC of the medium soil moisture content (50%FC) and the lowest Ic (0.76) was obtained from the control of the high soil moisture content (100%FC). A great significance was assigned to soil moisture for workability (Dexter and Bird, 2001). Critical moisture contents (dry and wet limits) should be specified for soil workability to reduce the tillage-induced destructions in soil structure (Obour et al., 2017). Obour et al. (2018) also reported increasing range of moisture for tillage with increasing organic matter contents. Soil workability is largely dependent on soil OM contents. In this study, Ic values increased by 13.0% with 2.5% VC and by 21.9% with 5% VC treatments. Significant increases were observed in Ic values of the soils with increasing VC doses. Ic designates soil consistency at a certain moisture content. The soils at plastic limit will have an Ic value of 1.0 and the soils at liquid limit will have an Ic of 0. The Ic values of between 0.75 – 1.00 indicate the optimal range of moisture. When the soils are cultivated at Ic value of <0.75, significant structural destruction will be encountered. Such conditions will reduce hydraulic conductivity, aeration, uptake of plant nutrients and negatively affect plant growth and microbial activity (Baumgartl, 2002). In this study, Ic values were greater than 0.75. Therefore, it was observed that the sandy-clay-loam soils could be cultivated without any structural deformations at FC or higher moisture contents with vermicompost application. Moisture content upper limits for optimal tillage without any structural destructions were suggested as 26.8%, 34.9% and 36.9% for 0%VC, 2.5%VC and 5%VC treatments, respectively.

Mueller et al. (2003) reported Ic of 1.15 and 90% of PL as the maximum soil moisture content for optimum tillage of cohesive soils. Dexter and Bird (2001) stated optimum moisture for soil workability as the moisture content in which the highest number of small aggregates can be obtained as a result of soil cultivation and this value is equal to approximately 90% of the PL. Gülser and Candemir (2006) reported optimum soil water contents as around the field capacity for workability. In another study, Gülser et al. (2009) studied soil moisture contents for suitable workability and reported clay content as between 72.30 - 79.40% and indicated that experimental soils could be cultivated without structural destructions at FC (40.4%) or at moisture contents of between 33.2 - 40.4%. In present study, calculated gravimetric water contents (W) for Ic values of 0.75, 1.00, 1.15 and %90 PL are presented in Figure 3. It seems that soil moisture contents at FC were suitable for the cultivation of soils. However, greater moisture contents were suggested as 26.8, 34.9 and 36.9% for 0% VC, 2.5%VC and 5%VC treatments, respectively. Petelkau (1984) stated that the most suitable soil cultivation takes place at humidity held at a matrix potential of -5 kPa and the moisture retained at this value varied between 50-65% in clay soils, 40-75% in loamy soils and 20-85% in loamy sand textured soils.

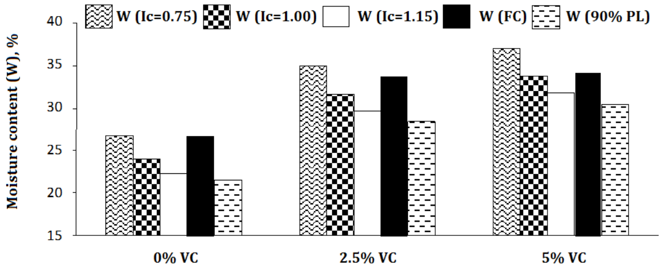

Figure 3. Soil moisture contents (W) at FC and different index of consistency values for suitable workability (VC: vermicompost, FC: field capacity. PL: plastic limit, Ic: consistency index)

Conclusion

Present findings revealed that VC treatments (0%VC, 2.5%VC and 5%VC) under different soil moisture contents (100%, 50% and 25%FC) increased liquid limit, plastic limit, plasticity index and consistency index of sandy-clay-loam soils as compared to the control treatment. Moisture content upper limits for optimal tillage without any structural destructions were suggested as 26.8%, 34.9% and 36.9% for 0%VC, 2.5%VC and 5%VC treatments, respectively. VC treatments increased Ic values as compared to the control. Ic values were greater than 0.75. Therefore, it was observed that the sandy-clay-loam soils could be cultivated without any structural deformations at FC or higher moisture contents with vermicompost application. Significant increases were observed in Ic values of the soils with increasing VC application rates. These findings clearly showed that VC treatments extended the range of field workability. It was concluded that addition of vermicompost under different soil moisture contents into a sandy-clay-loam soil significantly influenced soil mechanical properties. Present findings indicated that vermicompost applications in to sandy-clay-loam soil was useful for cultivation of soil.

Acknowledgement

The author would like to thank the Soil, Fertilizers and Water Resources Central Research Institute and Prof. Dr. Abdullah Baran and Çağla Temiz (PhD student) for providing working environment and facilities for this study.

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