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Improvements in aggregate stability of sediments supplemented with tea waste and farmyard manure

Mejoras en la estabilidad de los agregados de sedimentos enmendados con residuos de té y estiércol de granja
Melhorias na estabilidade dos agregados de sedimentos corrigidos com resíduos de chá e estrume

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ABSTRACT

The influence of organic matter amendments on soil aggregate stability is well known, but the corresponding changes in recently deposited sediment are not well documented. In this study, improvements in aggregate stability of recently deposited sediment (RDS) supplemented with farmyard manure (FYM) and tea waste (TW) were evaluated during an 18-week incubation period under controlled conditions. FYM and TW were applied to RDS at different rates (0%, 2.5%, 5%, 7.5%, 10%, 12.5% and 15% w/w), and aggregate stability was determined at different times of incubation (2nd, 4th, 6th, 8th, 10th, 14th, and 18th weeks) using wet sieving analysis. The results showed that the aggregate stability of RDS treated with TW was statistically significantly higher than those of samples treated with FYM. Aggregate stability increased with increasing rates of both FYM and TW. Aggregate stability reached the highest value at the end of the second week in FYM treated samples, and declined within the following incubation period. However, in the samples treated with TW, aggregate stability reached the highest value at the end of the eighth week. Since the results of this study clearly indicated that tea waste and farmyard manure input significantly increased the aggregate stability of RDS, it is suggested that TW and FYM could be used for structural stabilization of degraded soils.

RESUMEN

La influencia de las enmiendas de materia orgánica sobre la estabilidad de los agregados del suelo es bien conocida pero los cambios producidos en sedimentos recientemente depositados no está bien documentada. En este estudio se evaluaron las mejoras producidas en la estabilidad de los agregados de sedimentos recientemente depositados (RDS) enmendados con estiércol de granja (FYM) y residuos de té (TW) durante un period de incubación de 18 semanas bajo condiciones controladas. FYM y TW se aplicaron a los RDS en diferentes proporciones (0%, 2,5%, 5%, 7,5%, 10%, 12,5% y 15% en peso) y la estabilidad de los agregados se determinó a diferentes tiempos de incubación (2ª, 4ª, 6ª, 8ª, 10ª, 14ª y 18ª semanas) utilizando análisis de tamizado húmedo. Los resultados mostraron que la estabilidad de los agregados de los RDS enmendados con TW era más estadísticamente significativa que la de las muestras enmendadas con FYM. La estabilidad de los agregados se incrementó a medida que aumentaba la proporción de las enmiendas tanto de FYM como de TW. La estabilidad de los agregados alcanzó el valor máximo al final de la segunda semana de incubación para las muestras enmendadas con FYM y fue disminuyendo con el tiempo a lo largo del siguiente periodo de incubación. Sin embargo, en las muestras enmendadas con TW, la estabilidad de los agregados alcanzó el valor máximo al final de la octava semana. Como los resultados de este estudio muestran claramente que las enmiendas de residuos de té y de estiércol de granja aumentan significativamente la estabilidad de los agregados de sedimentos depositados recientemente, se sugiere que los residuos de té y el estiércol de granja podrían ser utilizados para la estabilización estructural de suelos degradados.

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RESUMO

A influência da aplicação de resíduos de materia orgânica na estabilidade dos agregados do solo é bem conhecida mas as alterações produzidas nos sedimentos recentemente depositados não está bem documentada. Neste estudo avaliaram-se as melhorias produzidas na estabilidade dos agregados de sedimentos recentemente depositados (RDS) a que se adicionou estrume (FYM) e residuos de chá (TW) durante um periodo de incubação de 18 semanas em condições controladas. FYM e TW aplicaram-se aos RDS em diferentes proporções (0%, 2,5%, 5%, 7,5%, 10%, 12,5% y 15% em peso) e a estabilidade dos agregados determinou-se a diferentes tempos de incubação (2ª, 4ª, 6ª, 8ª, 10ª, 14ª e 18ª semanas) utilizando a análise de crivagem por via húmida. Os resultados mostraram que a estabilidade dos agregados dos RDS corrigidos com TW era mais significativa estatísticamente que a das amostras corrigidas com FYM. A estabilidade dos agregados aumentou à medida que aumentava a proporção dos resíduos orgânicos tanto de FYM como de TW. A estabilidade dos agregados alcançou o valor máximo no final da segunda semana de incubação para as amostras corrigidas com FYM e foi diminuindo com o tempo ao longo do período de incubação seguinte. Contudo, nas amostras corrigidas com TW, a estabilidade dos agregados alcançou o valor máximo no final da oitava semana. Os resultados deste estudo mostram claramente que os residuos de chá e o estrume aumentam significativamente a estabilidade dos agregados de sedimentos depositados recentemente, pelo que se sugere que estes residuos possam vir a ser utilizados para conseguir a estabilização estrutural de solos degradados.

KEY WORDS
Aggregation, controlled conditions, degradation, organic matter

PALABRAS CLAVE
Agregación, condiciones controladas, degradación, materia orgánica

PALAVRAS-CHAVE
Agregação, condições controladas, degradação, matéria orgânica

1. Introduction

Soil's structural stability refers to the resistance of soil aggregates to the disintegrating influences of water and mechanical manipulation (Jury and Horton 2004). It is also one of the most important factors of soil resistance against degradation (Jozefaciuk and Czachor 2014). Aggregate stability influences macro scale physical behavior of soil such as erosion, infiltration, and permeability, thus it is used as an indicator of suitability of the soil structural condition for favorable crop production (Lal 2006).

Organic matter is the most important agent of soil aggregate stability, because organic carbon acts as a binding agent and as a nucleus in the formation of aggregates (Bronick and Lal 2005). Addition of organic matter help to increase resistance of aggregates against dispersive and dissolution actions of water through the formation of relatively strong intra-aggregate bonds (Paré et al. 1999). In respect to these remarks, the addition of organic matter has been used in the restoration of degraded soils for a long time (Rusinamhodzi et al. 2013; Hernández et al. 2015; Khaliq and Kaleem Abbasi 2015). Recent studies indicated that effects of organic matter addition to soil vary depending on organic matter sources (Ozdemir et al. 2007; Alagöz and Yilmaz 2009; Candemir and Gulser 2011; Turgut and Aksakal 2011; Karami et al. 2012; Yakupoglu and Ozdemir 2012; Hueso-González et al. 2014), application rates (Mbagwu 1989; Paré et al. 1999; Nyamangara et al. 2001; Jozefaciuk and Czachor 2014) and incubation times (Bravo-Garza et al. 2010). In most of these studies, farmyard manure, green manure or composts were used as an organic matter source, but the effects of tea waste on aggregate stability has been rarely studied (Candemir and Gulser 2011; Yakupoglu and Ozdemir 2012).

Sediment is described as solid particles generated by the disintegration process of organic and inorganic materials (Bortone 2006). Sediment from large erosion plots and a small watershed is frequently enriched in fines, that is, the fraction of clay and silt particles is greater in the sediment than in situ soil (Foster et al. 1985). The recent sediments accumulated in the dam reservoir areas are suitable for plant growth in terms of texture (Turgut et al. 2015), but they lost productivity because of deterioration in their physical and chemical properties due to erosion. Aggregate stability was found to be over 40% in studies conducted over degraded soils (Hernández et al. 2015; Khaliq and Kaleem Abbasi 2015; Mukherjee et al. 2014), and this is much higher in those found in studied recently deposited sediment (RDS). Therefore, RDS can be considered as a special case of extremely degraded soils. In accordance, the practices that improve the aggregate stability in RDS can also be suitable, and probably more effective, in improving extremely degraded soils.

The objectives of this study are; (i) to determine whether tea waste and farmyard manure applications can improve aggregate stability of RDS, (ii) to measure the effectiveness of tea waste and farmyard manure in improving aggregate stability, (iii) to compare the amounts of tea waste and farmyard manure applied to RDS, and (iv) to observe the changes in aggregate stability of RDS with elapsed time. In this research, it is expected that tea waste application can improve the aggregate stability of degraded soils as an alternative to commonly used farmyard manure application.

2. Materials and methods

The recently deposited sediment (RDS) samples were collected from the Borçka Dam reservoir built on the Çoruh River in Artvin, Turkey (**Figure 1**). Sedimentation had started soon after the dam began holding water in 2006. In 2013 another dam (the Deriner Dam) had started to retain water at about 40 km upriver of the Borçka Dam. As a result, water reaching the studied reservoir, and thus the water level, had decreased, thereby exposing sediment deposition areas on the reservoir banks (**Figure 2**).

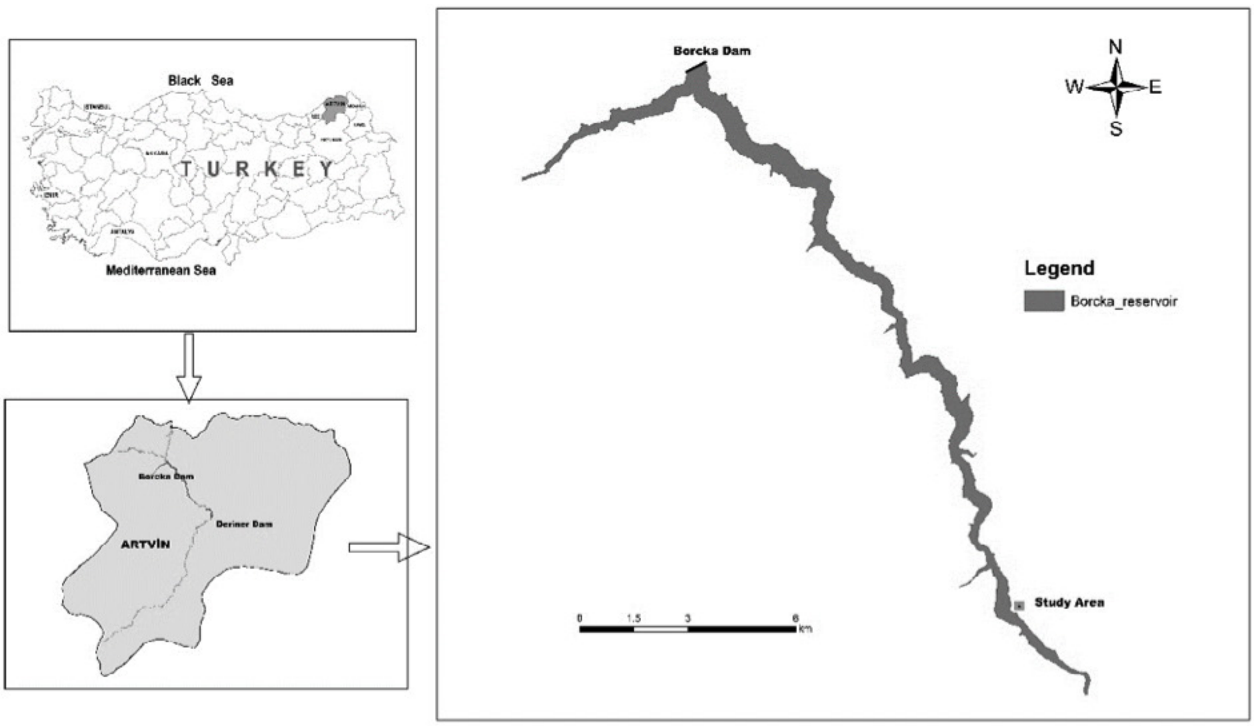

Figure 1. Location of the study area within the Borcka Dam reservoir.

Figure 2. Photos from the sediment deposition area.

At each of the 15 randomly selected sampling points, about 10 kg of RDS samples were collected from the top 20cm layer with a soil sampling auger. Some physical and chemical properties of RDS samples are given in **Table 1**. Two different organic amendments, tea waste and farmyard manure (FYM), were applied. The TW was obtained from the surpluses of tea factory and the FYM was provided from a cattle-rising farm in the region. After air drying, pulverizing in a blender and passing through a 2 mm sieve, total carbon, total nitrogen and total sulphur of the organic materials were identified using an elemental analysis device (an Elementar vario MACRO cube CHNS elemental analyzer). The measured chemical composition of TW and FYM is presented in **Table 2**. The study was conducted in a fully-controlled greenhouse condition.

Table 1. Some properties of the sediment used in this study

	Min	Max	Mean	SD	CV
Clay (%)	24.68	28.80	26.63	0.81	3.04
Silt (%)	37.68	43.93	40.43	1.51	3.73
Sand (%)	31.34	35.63	32.93	1.33	4.04
Organic matter (%)	1.23	1.35	1.28	0.03	2.34
pH	8.32	8.73	8.60	0.11	1.28
Aggregate stability (%)	4.52	6.32	5.66	0.68	12.01

Table 2. Chemical composition of tea waste (TW) and farmyard manure (FYM) used in the study

	TW	FYM
Total carbon (%)	47.32	29.06
Total nitrogen (%)	3.98	2.03
Total sulphur (%)	0.26	0.43
C:N	11.89	14.32
pH	5.77	9.29

The RDS obtained from reservoir site were air-dried in the laboratory, clods were broken and mixed until a homogenous mixture was obtained. The statistical design of the study was a split-split plot in randomized completed block with two replications (**Table 3**). The main plot was organic material sources and the subplot was application rates. The RDS were mixed with TW and FYM to make up a total of 2000 g of mixtures for each application rate. The percentages of TW and FYM used in the mixture were as follows: 0%, 2.5%, 5%, 7.5%, 10%, 12.5%, and 15%. Each mixture with two replications was placed in an apparatus consisting of 28 compartments each with 40 x 25 cm in size (**Figure 3**).

Table 3. The experimental design

10% TW	7.5% TW	5% TW	7.5% TW	2.5% TW	15% TW	0% TW
0% TW	2.5% TW	15% TW	12.5% TW	10% TW	12.5% TW	5% TW
7.5% FYM	0% FYM	15% FYM	7.5% FYM	10% FYM	12.5% FYM	2.5% FYM
15% FYM	12.5% FYM	5% FYM	0% FYM	10% FYM	2.5% FYM	5% FYM

During an 18-week incubation period following the addition of TW and FYM, the temperature of the greenhouse was maintained in the range of 25 to 28 ºC while the moisture content of the mixtures was kept at field capacity (23% w/w). Aggregate stability was determined at the ends of 2, 4, 6, 8, 10, 14 and 18 weeks of each treatment. In these periods, the six subsamples were taken from each replication and aggregate stability analysis was performed on them. Yoder wet-sieving method (Jacob et al. 2002) was used for identifying the aggregate stability (1-2 mm aggregates). For this purpose, 4 g of the mixed samples were placed in 0.25 mm sieves and lowered into the water to saturate. After wetting, samples were sieved in distilled water at a rate of 30 times min^{-1} for 3 min. The remaining samples on each sieve were dried at 105 °C for 24 h, and then sand and aggregates were separated adding calgon (sodium hexametaphosphate). After correcting for sand particles, the fraction of aggregates larger than 0.25 mm was expressed as WSA > 0.25 mm. The wet combustion method (Sparks et al.

Figure 3. The apparatus used in the study.

1996), and hydrometer method (Gee et al. 1986) were used for identifying the organic matter content, and particle size distribution of the RDS, respectively. The pH was measured in 1:2.5 sediment-water suspensions (Conklin 2005). Differences in aggregate stability between TW and FYM applications and their application were examined by one-way ANOVA. Student's t-test at 5% level probability was used to test the differences between means of individual treatments. The JMP 5.0 software was employed for all of the statistical tests (JMP 2007).

3. Results and discussion

TTea waste (TW) and farmyard manure (FYM) applications significantly increased the aggregate stability of recently deposited sediment (RDS) compared with the control group ($p < 0.05$; **Table 4**). The aggregate stability increased to 20.29% with TW and 17.41% with FYM applications (**Table 4**) compared to 5.66% in the control treatment. This increase can be explained by the important role of organic matter in aggregation. It is well known that organic matter flocculates the mineral particles and contributes stable aggregate formation by acting as a cementing agent (Bronick and Lal 2005). Similar to our findings, previous research on degraded soils showed that farmyard manure and green manure greatly increased aggregate stability (Bandyopadhyay et al. 2010; Annabi et al. 2011; Karami et al. 2012; Wang et al. 2015). Despite the absence of any study directly comparing the effect of both TW and FYM on aggregate stability, the studies comparing the aggregate stability of soils supplemented with green manure and FYM reported that FYM increased aggregate stability dramatically shortly after the addition of organic matter (Karami et al. 2012). However, in long-term studies, green manures were reported to be more effective on water stable aggregates than FYM (Annabi et al. 2011; Turgut and Aksakal 2011).

Both the TW and FYM increased aggregate stability at all application levels, but their effectiveness was slightly different from each other. A gradual and statistically significant increase in aggregate stability was observed in TW ($p < 0.01$) and FYM ($p < 0.01$). An increase in aggregate stability was sharper in FYM than in TW at the initial application dose (2.5%), but unlike in TW, it had formed a plateau up to 10% before gradually increasing in the remaining two application doses. Except for the 2.5% application dose, increase in aggregate stability was higher for TW than those observed for FYM (**Table 4**). Our findings agreed with the results reported by Paré et al. (1999), Curtin and Mullen (2007), Turgut and Aksakal (2011) and Karami et al. (2012). They reported that aggregate stability increased depending on application doses of farmyard manure and various green wastes. In its decomposition process, organic material releases polysaccharides and organic acids that result in the formation of stable macroaggregates (> 0.25 mm) by binding soil particles (Oades 1984; Tisdall and Oades 1982). Therefore, the higher the added organic matter is the greater the stable aggregate formation.

With respect to the elapsed time from organic matter application, both TW and FYM showed differences in increasing the rate of aggregate stability. With TW application, aggregate stability increased from the second week and continued until the eighth week. However, after this point, a non-regular change occurred in the aggregate stability as shown in **Table 4**. The differences between the elapsed times were not significant ($p > 0.05$). Similar to the TW, in the case of FYM addition, aggregate stability tended to increase from the second week, but unlike TW, it reached its highest value in the fourth week. However, the rate started to decrease after the fourth week (**Table 4**). The differences between the elapsed time of the application were found to be statistically significant ($p < 0.01$). It was stated in similar studies that the elapsed time needed for the aggregate stability to reach its highest value varies, depending on the type of organic material and study conditions. Abiven et al. (2009) found that aggregate stability reached the highest value 30-100 days after addition of plant-based organic wastes while it was 14-60 days in the case of FYM application under similar greenhouse conditions. Researchers suggested that the rate of decomposition of FYM in soil is higher than plant-based organic wastes (Mohanty et al. 2011; Saikia et al. 2015). This might explain why the aggregate stability reached the highest value in a shorter time and tended to decrease depending on the elapsed time for the FYM application in our study. In addition, in the case of TW application, it takes longer for the aggregate stability to reach the highest value and it is not tended to decrease in the period of elapsed time, which may be associated with a lower decomposition rate of the TW.

Table 4. Effects of treatments, application doses and elapsed time from application on aggregate stability

Sources		Aggregate stability (%)	F values
Treatments	Control	5.66c	3.91*
	TW	20.29a	
	FYM	17.41b	
Application doses for TW	Control	5.66 E	21.44**
	2.5%	12.56 D	
	5.0%	21.44 C	
	7.5%	22.95 BC	
	10%	23.08 BC	
	12.5%	27.40 B	
	15%	30.67 A	
Application doses for FYM	Control	5.66 D	34.13**
	2.5%	16.93 C	
	5.0%	16.97 C	
	7.5%	17.79 C	
	10%	18.23 BC	
	12.5%	23.18 A	
	15%	24.91 A	
Elapsed time from application for TW	2nd week	18.65	1.12ns
	4th week	20.30	
	6th week	22.19	
	8th week	25.50	
	10th week	20.33	
	14th week	26.11	
	18th week	22.99	
Elapsed time from application for FYM	2nd week	20.09 AB	3.97**
	4th week	24.62 A	
	6th week	22.07 AB	
	8th week	20.82AB	
	10th week	17.55 BC	
	14th week	19.38 B	
	18th week	13.16 C	

* indicates significance at the 95% level of probability.
** indicates significance at the 99% level of probability.
ns indicates insignificance.
Means with capital and small letters indicate significant differences, 0.01 and 0.05, respectively.
TW: tea waste.
FYM: farmyard manure.

4. Conclusions

The results of this study clearly indicated that; (i) addition of the TW and FYM resulted in significant improvement in aggregate stability of RDS, (ii) the TW is more effective than FYM in terms of aggregate stability, (iii) aggregate stability, increased depending on application doses of both TW and FYM, and (iv) the FYM increased aggregate stability to the highest value in a shorter time while it took a longer time to reach the highest value in the TW treatment. As a result of this study, it was concluded that both TW and FYM applications could be used for the improvement of physical properties of degraded soils.

In practice the significance of the findings is twofold. First, in areas with steep topography such as Artvin, where new agricultural plots are created by terracing and suitable soil resources are very scarce for this practice, fine-grained sediments can be a good source of plantation medium with added organic amendments. Both tea waste and farmyard manure are abundant in this region because of its proximity to tea plants and cattle-raising farms. Second, sediment accumulation reduces water storage capacity of dam reservoirs, and thus the benefits of a dam. Removing sediments from reservoirs for agricultural purposes can help in increasing the sustainability of the benefits expected from a dam.

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