CHANGES IN PROPERTIES OF A CLAYEY SOIL AFTER ADDING COMPOSTED AND UNCOMPOSTED GYTTJA

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Abstract. This study presents an incubation experiment that investigates the effects of adding composted and uncomposted gyttja on a clayey soil's structural stability and other properties. For this purpose, 3% (w/w) of the composted and uncomposted gyttja was added to pots with and without grass pea (*Lathyrus sativus* L.) seeds and incubated for nine months under greenhouse conditions. In the third, sixth, and ninth months of the experiment, soil samples were tested. The results show that the time elapsed during the incubation period greatly affected the physical (average weighted diameter, aggregate stability, and volume weight) and chemical (pH, EC, organic matter, N, P, K, Ca, Mg, and Na) properties of the soil. The input of composted and uncomposted gyttja caused significant changes in soil properties, but these were less pronounced in soils with composted gyttja.
Keywords: *aggregate stability, mean weight diameter, soil conditioner, Vertisol*

Abbreviations: BD: dry bulk density, Ca: extractable calcium in ammonium acetate, C-gyttja: composted gyttja, EC: Electrical conductivity value corrected for 25 °C, N: total nitrogen, K: extractable potassium in ammonium acetate, MDW: mean weight diameter, Mg: extractable magnesium in ammonium acetate, Na: extractable sodium in ammonium acetate, ns: not statistically significant, P: available phosphorus for plants, pH: soil reaction, SOM: soil organic matter content (w/w), UnC-gyttja: uncomposted gyttja, WAS: wet aggregate stability

Introduction

Since the industrial revolution, exponential population growth, urbanization, changes in production methods, and consumption habits have greatly increased environmental pollution. Waste is generated from many types of businesses, including the energy sector, which has a vital importance in the modern age. For thermal power plants, gyttja is waste material that is difficult to deal with. In order to extract lignite to operate thermal power plants, a layer called gyttja must be removed. It is usually 10–15 m thick and found at depths of 20–40 m. Pickling of this emerging gyttja is a process that needs to be managed from an environmental point of view.

Gyttja is a muddy freshwater deposit located near or under a lake. The term was first mentioned in 1862 by the Swedish scientist Hampus von Post. He defined gyttja as a

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light-gray to brown-black deposit made up of plankton particles in eutrophic waters, mollusk shells, insect shells, high plant content, pollen spores, and mineral particles (Stankevica et al., 2013; Yakupoglu et al., 2013). Gyttja may contain minerals (Miroslaw-Grabowska and Gasiorowski, 2010; Jarnuszewski and Meller, 2009) and has up to 50% $CaCO_3$ depending on its depth (Larsson, 1990; Becker et al., 2004).

During coal production, the average amount of gyttja extracted from lignite by the Afsin-Elbistan facilities operating in Turkey is around 14×10^6 Mg. The Afsin-Elbistan coal power plant, operating with the A and B units, has a reserve of 1.8×10^9 Mg gyttja, which will reach $3.5\text{-}4\times10^9$ Mg once the C and D units become operational (Saltali and Yildirim, 2016). Afsin-Elbistan lignite mines cover an area of approximately 12 000 ha (Munsuz and Akyildiz, 1979) and are located in the basin of Turkey's largest lignite reserve (Avci, 2005). Lignite extraction continues to be carried out with the open operating method as part of the power plant project in this basin. Aside from the A and B units of the power plant that are already operational, C, D, E and F sectors can be found (Gunalay, 1971) in another area. Removing gyttja is a process that must be managed.

Organic content of gyttja in this basin is > 20% (Karaca et al., 2006; Torun, 2009; Demirkiran and Cengiz, 2010). Heavy metal content in the soil does not exceed acceptable limits. When added to the soil in appropriate doses, gyttja may be used as a soil regulator. Soils cultivated in the world generally have low levels of organic matter (Edwards et al., 2000; Robertson et al., 2014; Bischoff et al., 2016) and this also applies to Turkey as well (Aydin et al., 2017). The most common way to address this deficiency is by adding vegetable and animal organic matter (Candemir and Gulser, 2011), but they may not be available in the required amounts. On the other hand, gyttja is abundant and does not have many other uses, so it has potential to be used on agricultural fields (Tamer and Karaca, 2006).

Although there have been many studies of gyttja as a soil conditioner (Torun et al., 2003; Stankevica et al., 2014; Demir et al., 2017; Namli et al., 2017, 2019; Yuce and Yakupoglu, 2017), these studies have mostly focused on plant nutrition and contamination caused by gyttja. However, the gyttja in these studies was only broken down into smaller particles and not composted, which is how it is found in nature. Adding gyttja to soil without composting may result in delayed effects and inadequate improvements in the physical properties of the soil such as aggregation compared to other organic materials (Musuz and Akyildiz, 1979). Natural organic materials should be composted and then added to the soil in order to provide faster and longer lasting effects, as is done for vegetable and animal organic materials (Del Buono et al., 2011; Gulser et al., 2015; Mpeketula and Snapp, 2018; Mekki et al., 2019).

This study presents the results of an incubation experiment. Adding composted and uncomposted gyttja to clayey soil changed its physical and chemical properties. Erosion control is also important in clay soils because perhaps they are relatively hard to erode but are easily transported when eroded. This soil was used a substrate to grow grass pea (*Lathyrus sativus* L.).

Materials and methods

Soil

As reported by Ersahin and Karahan (2015), the soils used in the incubation experiment were obtained from cultivated land in the Topcu Village in the Yozgat city, Turkey (44018175 N, 654331 E, 1267 m asl). Its properties are given in *Table 1*

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(Yakupoglu, 2018). It is clay-based Vertisol (47.6% clay, 13.8% silt, 38.6% sand), slightly salty (EC, 3.97 dS m^{-1}), has a neutral pH (7.09), is moderately calcic (7.15% $CaCO_3$), and has a medium organic matter content (2.49%). The total N content is 0.15% and the available P_2O_5 is 179.3 ppm.

Table 1. *Properties of the Vertisol before the experiment (Yakupoglu, 2018)*

pH	EC (dS m^{-1})	SOM (%)	$CaCO_3$ (%)	Total N (%)	P_2O_5 (ppm)	Clay (%)	Silt (%)	Sand (%)	Texture class
7.09	3.97	2.49	7.15	0.15	179.3	47.6	13.8	38.6	C

Gyttja and gyttja compost

The raw gyttja used in the experiment was obtained from the Kahramanmaras Afsin-Elbistan Lignite Operations Directorate. Before the experiment, some of the gyttja was composted with olive oil production waste called pirina (pH, 5.7; C/N 50, organic carbon, 48.2%) with microbial inoculation for eight months, according to the aerobic windrow method (Kavdir and Killi, 2008). Gyttja and pirina were mixed at a 1:1 ratio based on dry weight. In the experiment, both composted and uncomposted gyttja were used. Their properties are given in *Table 2*, which shows that composting gyttja improved its physical properties. Bulk density decreased from 0.65 to 0.59 Mg m^{-3}, total porosity increased from 71 to 82%, and water holding capacity increased from 206 to 270%. In addition, the negative properties of gyttja such as high total $CaCO_3$ content and improper particle size distribution were largely eliminated.

Table 2. *Physical and chemical properties of composted and uncomposted gyttja*

Properties	Value	
	Uncomposted gyttja (Yakupoglu et al., 2013)	Composted gyttja
Ash (%)	61.79	66.2
Organic Carbon (%)	22.16	19.6
C/N	12.6	17.07
pH	7.01	6.42
$EC_{25\,°C}$ (dS m^{-1})	0.77	2.24
$CaCO_3$ (%)	39.1	7.75
Bulk density (Mg m^{-3})	0.65	0.59
Particle density (Mg m^{-3})	2.25	2.21
Total porosity (%)	71	82
Water holding capacity (%)	206	270
Total N (%)	1.76	1.15
Available P (µg g^{-1})	19.4	44.2
Total K (µg g^{-1})	183	92
Total Ca (µg g^{-1})	122628	13892
Total Mg (µg g^{-1})	2348	3734
Total Na (µg g^{-1})	183.8	5.96
Total Fe (µg g^{-1})	53.4	864
Total Cu (µg g^{-1})	6.62	145
Total Zn (µg g^{-1})	5.86	307
Total Mn (µg g^{-1})	28.7	0.54

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Experimental design

Incubation trials were carried out under controlled conditions (22 ± 0.5 °C), in an air-conditioned unit with three repetitions. For this purpose, 1500 g of soil (dry weight) was sifted through a < 4 mm sieve, put into plastic pots, and homogenously mixed with 3% dry weight of composted or uncomposted gyttja. Five grass pea (*Lathyrus sativus* L.) seeds were planted in each pot, the soil was watered until moisture content reached field capacity and the pots were left to incubate. During incubation, moisture content was kept at field capacity with periodic watering. No fertilizers or pesticides were added. Pots without gyttja comprised the control group. Incubation lasted nine months and the trial consisted of a total of 54 pots. In the third, sixth and ninth months of the experiment, changes in physical and chemical properties of the soils were tested.

Physical and chemical soil analyses

We measured soil reaction (pH) and electrical conductivity (EC) in a 1:2.5 soil-pure water suspension by Hanna pH-meter and EC-meter, respectively (Rowell, 1996), soil organic matter (SOM) by the modified Walkley-Black method (Nelson and Sommers, 1982), and total nitrogen (N) by the Kjeldahl method using Gerhardt automatic steam distillation system (Kacar, 1994). Available phosphorus (P) was determined spectrophotometrically (Rayleigh) from $NaHCO_3$ extractions (Olsen et al., 1954) and the exchangeable cations (Ca, Mg, K and Na) were determined from 1 N NH_4OAc extractions (Thomas, 1982). Bulk density was determined using intact soil cores taken with Eijkelkamp 100-cm^3 steel cylinders (Blake and Hartge, 1986). Aggregate stability (WAS) was determined by the wet sieving method (Kemper and Rosenau, 1986) and the mean weighted diameter (MWD) was determined by the dry sieving method (Demiralay, 1993) using Eijkelkamp equipment. All of the experimental procedures were repeated three times and results were averaged.

Statistics

The effects of the variables were tested with ANOVA and the Duncan test ($\alpha = 0.05$) was used to compare averages. Statistical evaluations were done in SPSS 22.0 (Efe et al., 2000).

Results and discussion

Effects of composted and uncomposted gyttja applications on soil properties

Physical and chemical analysis results performed at the end of the third, sixth, and ninth months of the incubation experiment are given in *Table 3*. This shows changes in soils with composted and uncomposted gyttja. For example, at the end of the third month, SOM was 3.08% for the control pot but 4.48% in pots with composted gyttja and 4.25% with uncomposted gyttja. Hence SOM was on average 5.11% higher in pots with composted gyttja and 5.33% higher in pots with uncomposted gyttja. At the end of the sixth and ninth months, SOM was also higher in pots with gyttja than in control pots, but after that SOM tended to decrease.

The average N in control pots with grass pea seeds decreased to 0.563% at the end of the ninth month, but the N content of pots with composted gyttja was maintained at

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0.960%. At the end of the ninth month, average changeable Ca concentrations were around 5700 ppm, but remained above 6000 ppm at the end of the sixth and ninth months in pots with composted gyttja.

When *Table 3* is examined in terms of BD, which is one of the soil physical properties, it is understood that in all three sampling periods, decreases in BD values can be achieved by applying regulators in pots with and without plants. WAS, which is used as an evaluation index for the sensitivity of soils to water erosion, decreased from 55.3% at the end of the third and sixth months to 49.3% at the end of the ninth month.

Table 3. *Mean values of measured dependent variables (C-gyttja: composted gyttja, UnC-gyttja: uncomposted gyttja)*

Month	Plant	Treatment	SOM (%)	pH	EC (dS m^{-1})	N (%)	P (ppm)	Ca (ppm)
3rd	No plant	Control	3.08	7.95	0.653	0.583	7.41	5878
		C-gyttja	4.48	7.90	0.688	0.723	7.08	6062
		UnC-gyttja	4.25	7.87	0.671	0.830	8.38	5978
	Grass pea	Control	2.74	7.90	0.618	0.569	6.29	5843
		C-gyttja	5.11	7.92	0.663	0.960	7.22	6197
		UnC-gyttja	5.33	7.87	0.636	0.837	7.22	6065
6th	No plant	Control	3.02	7.94	0.627	0.600	7.35	5825
		C-gyttja	4.21	7.90	0.660	0.730	7.38	6159
		UnC-gyttja	4.83	7.94	0.680	0.827	9.11	5944
	Grass pea	Control	2.90	7.94	0.576	0.580	6.85	5923
		C-gyttja	5.92	7.99	0.662	0.957	7.05	6184
		UnC-gyttja	4.88	7.90	0.692	0.730	7.80	6027
9th	No plant	Control	3.01	7.89	0.699	0.583	7.03	5851
		C-gyttja	3.79	7.87	0.755	0.717	7.02	6022
		UnC-gyttja	3.82	7.84	0.811	0.823	8.87	5935
	Grass pea	Control	2.62	7.92	0.737	0.563	6.97	5792
		C-gyttja	4.23	7.94	0.739	0.960	7.09	6138
		UnC-gyttja	3.21	7.89	0.781	0.664	7.87	6037
Month	**Plant**	**Treatment**	**Mg (ppm)**	**K (ppm)**	**Na (ppm)**	**BD (Mg m^{-3})**	**WAS (%)**	**MWD (mm)**
3rd	No plant	Control	2017	375	41	1.04	55.3	1.514
		C-gyttja	1816	385	40	0.99	64.4	2.057
		UnC-gyttja	1933	492	44	0.98	65.7	2.497
	Grass pea	Control	1778	384	47	1.07	52.3	1.551
		C-gyttja	1811	396	44	1.00	64.9	2.220
		UnC-gyttja	1888	523	50	0.99	72.8	2.560
6th	No plant	Control	2042	361	40	1.03	55.3	1.317
		C-gyttja	1876	371	39	0.99	72.0	1.789
		UnC-gyttja	1852	491	44	0.98	71.8	1.889
	Grass pea	Control	1734	381	46	1.05	55.2	0.997
		C-gyttja	1782	380	44	0.99	77.8	2.047
		UnC-gyttja	1862	518	50	1.00	62.5	2.119
9th	No plant	Control	2046	354	40	1.06	49.3	1.502
		C-gyttja	1869	369	39	1.01	62.5	1.700
		UnC-gyttja	1837	477	44	1.02	67.9	1.893
	Grass pea	Control	1802	369	46	1.07	48.5	1.123
		C-gyttja	1776	366	44	1.01	70.0	2.133
		UnC-gyttja	1854	511	50	1.06	61.1	1.737

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WAS for pots without plants with composted gyttja were maintained around 70% at the end of both the sixth and ninth months.

Table 3 indicates changes in many properties of the test soils. ANOVA tests if sampling time, grass pea cultivation, or the fact that gyttja had been composted had an impact on these changes (*Table 4*). There were effects due to sampling time on pH, K and BD ($p < 0.05$) and on SOM, EC, WAS, and MWD ($p < 0.001$). Time, as a source of variation, did not affect the remaining variables statistically. In other words, changes over time in N, P, Ca, and Na concentrations were not statistically significant.

Table 4. *Results of ANOVA showing the effect of variation sources on some soil properties*

Variation source	Dependent variables											
	SOM	**pH**	**EC**	**N**	**P**	**Ca**	**Mg**	**K**	**Na**	**BD**	**WAS**	**MWD**
Time	***	*	***	ns	ns	ns	ns	*	ns	*	***	***
Conditioner	***	*	***	***	***	***	ns	***	***	***	***	***
Plant	*	ns	ns	***	***	*	***	***	***	ns	ns	ns

*P < 0.05; **P < 0.01; ***P < 0.001

Table 5 shows the results of Duncan multiple-range tests of the variation sources for the measured averages. According to this table, there was no significant change in SOM at the end of the third (4.16a) and sixth (4.29a) months, but it did decrease by the end of the ninth month (3.44b); this difference was statistically significant. The pH of the soil was highest in the sixth month (7.93a) and there was no statistically significant difference between the third and ninth months. EC reached its peak at the end of the ninth month (0.753a), but was statistically identical after the third and sixth months.

Table 5. *Comparison of dependent variable means with the Duncan test (α = 0.05) (C-gyttja: composted gyttja, UnC-gyttja: uncomposted gyttja)*

Dependent variable	Variation source					
	Month			Conditioner		
	3rd	**6th**	**9th**	**Control**	**C-gyttja**	**UnC-gyttja**
SOM (%)	4.16a	4.29a	3.44b	2.89b	4.62a	4.38a
pH	7.90b	7.93a	7.89b	7.92a	7.91a	7.88b
EC (dS $m^{-1)}$	0.654b	0.649b	0.753a	0.651b	0.694a	0.711a
N (%)	ns	ns	ns	0.579c	0.841a	0.785b
P (ppm)	ns	ns	ns	6.99b	7.15b	8.22a
Ca (ppm)	ns	ns	Ns	5852c	6127a	5997b
Mg (ppm)	ns	ns	Ns	ns	ns	ns
K (ppm)	425a	417ab	407b	370b	377b	502a
Na(ppm)	ns	ns	Ns	43b	42b	47a
BD (Mg m^{-3})	1.01b	1.00b	1.04a	1.05a	0.99b	1.00b
WAS (%)	62.5b	65.7a	59.9c	52.6c	68.6a	66.9b
MWD (mm)	2.066a	1.692b	1.681b	1.333b	1.990a	2.115a

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Changeable K decreased over time and was statistically different in the third and ninth months. The lowest BD values were at the end of the third (1.01b Mg m^{-3}) and sixth (1.00b Mg m^{-3}) months, but higher (1.04a Mg m^{-3}) at the end of the ninth month. The WAS average was highest at the end of the sixth month (65.7a%) and the lowest was at the end of the ninth month (59.9c%). At the end of the sixth and ninth months, MWD was statistically the same; but at the end of the third month, it was higher; this difference was significant (2.066a mm).

According to *Table 5*, SOM, EC, and MDW were not affected by composting. Both composted and uncomposted gyttja were statistically different from the control. The highest total N (0.841a%), Ca (6127a ppm), and WAS (68.6a%) were from pots with composted gyttja.

The results show that adding gyttja affected Mg and improved other soil properties. Although adding organic materials can significantly improve soils (Eigenberg et al., 2002; Ozdemir et al., 2009; Yakupoglu and Ozdemir, 2012; Gülser et al., 2015), they should not result in extreme values, especially in agricultural soils. Adding gyttja generally affected the measured variables positively, which leads us to a comparison of the effects of composted and uncomposted gyttja.

Effects of composted and uncomposted gyttja applications on soil structural stability

Since changes in structural stability are closely related to organic matter content (Barthes et al., 1999; Zhang et al., 2005; Tejada and Gonzalez, 2007; O'Brien and Jastrow, 2013; Cates et al., 2016), it is appropriate to evaluate the effects of organic regulators such as gyttja on structural strength and SOM. Adding gyttja improved levels of organic matter in the soil and as a result, there were other changes in WAS and MWD, which are indicators of structural resilience. The time-dependent changes in SOM, WAS, and MWD in pots with composted and uncomposted gyttja are shown in *Figures 1–3*. *Figure 1* shows greater organic matter compared to control. The highest SOM values were reached at the end of the sixth month in pots with composted gyttja where grass pea was grown. Pots with uncomposted gyttja had higher SOM than control pots, but not as high as in pots with composted gyttja. In general, the decrease in SOM in the first six months in pots without plants was higher than in pots with plants. This can be attributed to the gradual decomposition of roots during the first six months, which contributed to the soil's SOM. At the end of the ninth month, SOM in pots with composted and uncomposted gyttja were similar, suggesting that plant roots were mineralized by then.

According to *Figure 2*, the highest WAS values were from samples taken in the sixth month from pots with plants and composted gyttja (77.8%). At the end of the ninth month, the highest WAS values were in pots with composted gyttja, with or without plants. Uncomposted gyttja was also successful in increasing WAS compared to the control, but in these pots, WAS decreased dramatically after the sixth month. This tracks changes in SOM content.

According to *Figure 3*, the highest MWD in both pots with (2560 mm) and with plants (2497 mm) were at the end of the third month in soils with uncomposted gyttja. However, it should be noted that after adding uncomposted gyttja, there were dramatic decreases in MWD over time. Pots with composted gyttja were also been successful in increasing MWD compared to the control. MWD reductions were slower, especially in pots with plants.

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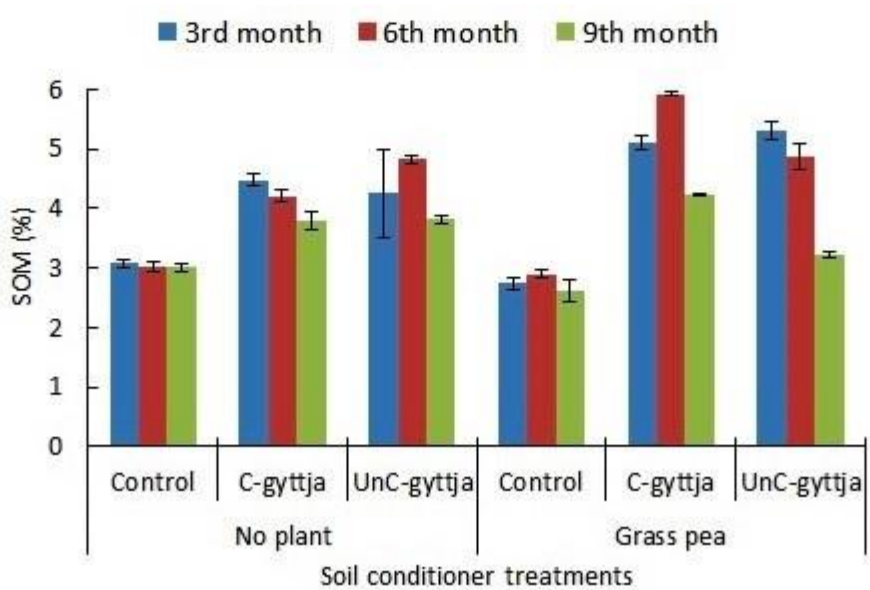

Figure 1. *Changes in SOM of control, composted gyttja (C-gyttja) and uncomposted gyttja (UnC-gyttja) treatments (Error bars represent the standard deviation of the replicates from the mean)*

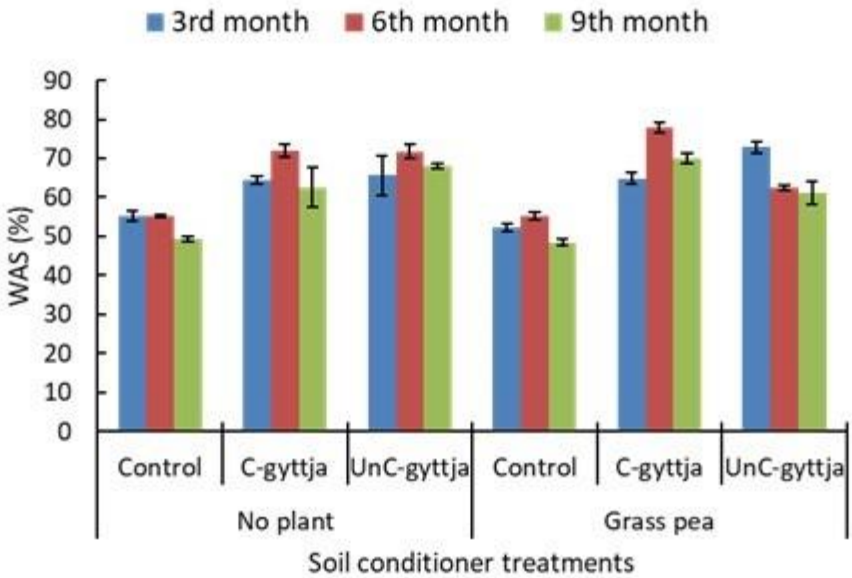

Figure 2. *Changes in WAS of control, composted gyttja (C-gyttja) and uncomposted gyttja (UnC-gyttja) treatments (Error bars represent the standard deviation of the replicates from the mean)*

These results were achieved by adding organic material to the soil, which increased SOM, namely in pots with added gyttja and grass pea roots. The hydrophobic part of the organic substance, which does not have a uniform distribution, can slow water entry into the aggregate and increase resistance of certain parts of the aggregate against water dispersion, due to this water repellence feature (Varadachari et al., 1991; Miller et al., 2019). This would increase WAS. On the other hand, the degree of hydrophobicity of organo-mineral particles determines their ability to interact with water due to

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hydrophobic bonds. Due to the formation of hydrogen bonds, the formation of stable aggregates to water or the tendency to be subjected to peptization would emerge. Hydrophobic humus substances thus affect the stability of the aggregate with water as well as the formation of structural bonds (Piccolo and Mbagwu, 1999; Whalen et al., 2003; Milanovsky et al., 2013). This explains why the organo-mineral structures formed in soils with composted gyttja are stronger than those in soils with uncomposted gyttja. In turn, this explains why WAS was higher in soil with composted gyttja. In the first three months, uncomposted gyttja was more successful in increasing MWD, but thereafter, composted gyttja was more successful, especially in pots with plants. MWD is used as an index for soil sensitivity to wind erosion. Since uncomposted gyttja increases MDW in the short term, it would be better for semi-arid regions such as Topçu. For medium to long term processes, composted gyttja is better.

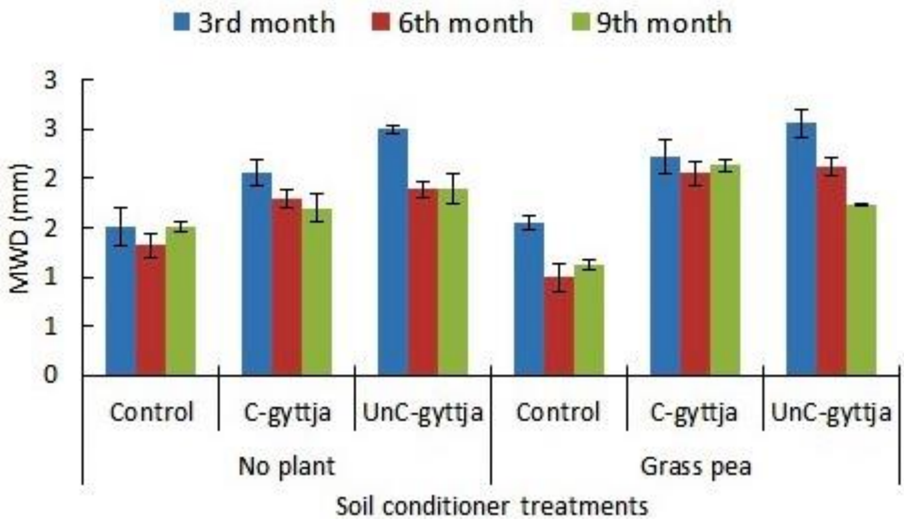

Figure 3. *Changes in MWD of control, composted gyttja (C-gyttja) and uncomposted gyttja (UnC-gyttja) treatments (Error bars represent the standard deviation of the replicates from the mean)*

Conclusions

When composted gyttja is added to cultivated soil, it does not result in extreme soil values. It increases WAS more than uncomposted gyttja. If the goal is to combat short-term wind erosion, uncomposted gyttja is more effective, but for long-term soil health, composted gyttja is better. Adding composted gyttja is more effective than uncomposted gyttja, since composting is an effective way to reduce its environmental damage as a waste product. Gyttja compost, which was prepared for this study, can be applied to plowed agricultural fields where forage crops are grown in semi-arid regions. Before adding composted gyttja to large areas, it is necessary to investigate the effects on different soils in each field. Only one-year forage crop (*Lathyrus sativus* L.) was cultivated in this study, and the changes caused by composted gyttja in the structural stability and some physico-chemical properties of the soil under grass pea were investigated. The effects of composted gyttja, especially reducing soil and water losses, should be investigated under different land and climate conditions. Changes in yield should be monitored and these studies should test different compost ratios doses and management techniques, which should be developed for each region.

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